Rothamsted Experimental Station
Harpenden

LAWES AGRICULTURAL TRUST

IMPERIAL MYCOLOGICAL INSTITUTE
FEB 1947

REPORT
for
THE WAR YEARS
1939-1945

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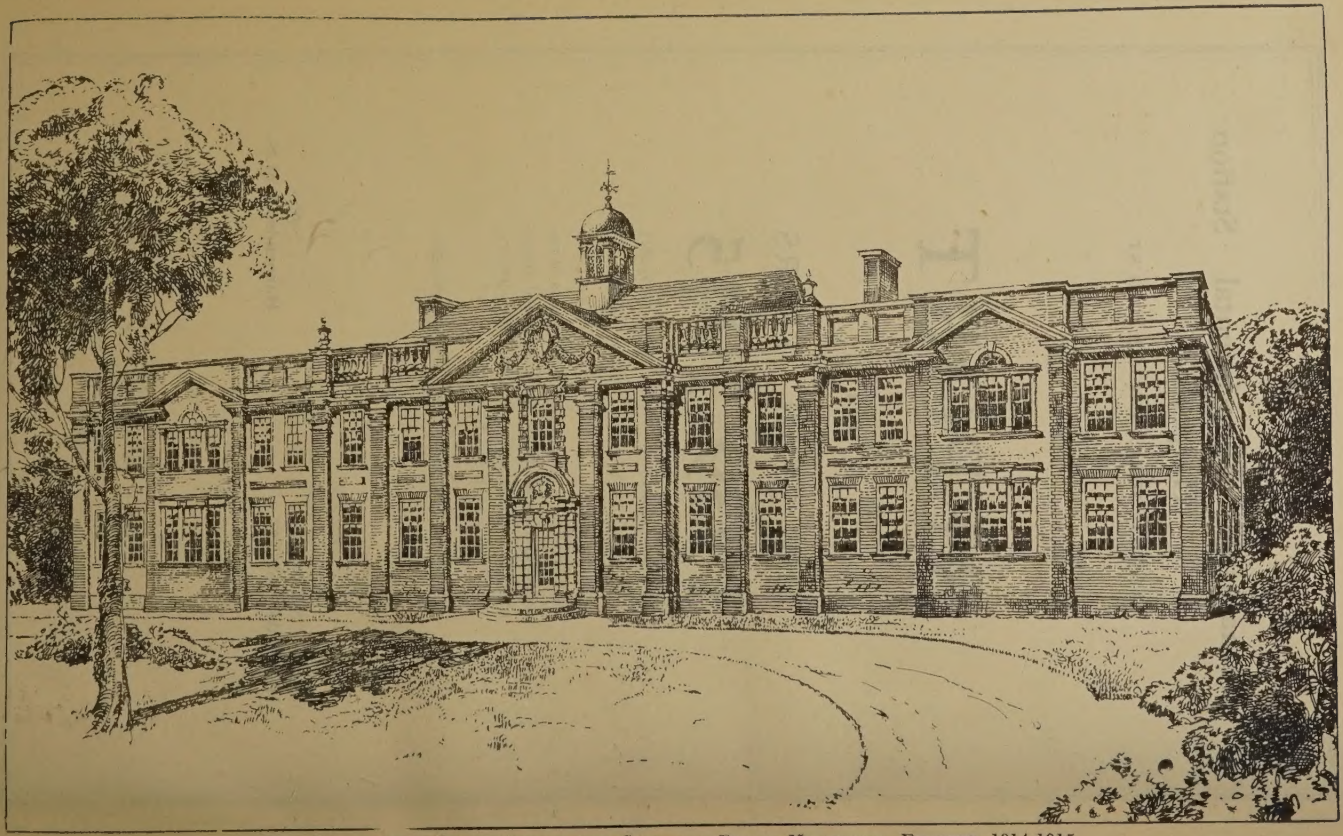

THE ROTHAMSTED LABORATORIES FOR SOIL AND PLANT NUTRITION, ERECTED 1914-1915.

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The Lawes Agricultural Trust

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DR. W. G. OGG, M.A. (Secretary)

The Royal Agricultural Society of England has not yet appointed a representative to succeed the late Colonel Wheatley.

Changes in the Lawes Agricultural Trust Committee during the war years have been as follows :-

DR. E. F. ARMSTRONG, F.R.S. (Treasurer), died December, 1945
PROFESSOR V. H. BLACKMAN, M.A., Sc.D., F.R.S. (Treasurer), resigned June, 1943
SIR J. B. FARMER, M.A., D.Sc., F.R.S., resigned October, 1939, died January, 1944
PROFESSOR A. V. HILL, Sc.D., F.R.S., resigned November, 1944
SIR GUY A. K. MARSHALL, C.M.G., F.R.S., resigned October, 1942
COL. C. J. H. WHEATLEY, died November, 1943

The Incorporated Society for Extending the Rothamsted Experiments

The purpose of this Society is to collect funds for continuing and extending the work of the Rothamsted Station.

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THE RIGHT HONOURABLE LORD CLINTON, P.C., G.C.V.O., D.L. } (Vice Chairmen)
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Rothamsted Experimental Station Staff

DECEMBER, 1945

Director: W. G. Ogg, M.A., B.Sc., B.Sc.(Agric.), Ph.D.
Assistant Director: B. A. Keen, D.Sc., F.Inst.P., F.R.S.
Secretary: W. Barnicot, M.B.E.

Physics Department—

Head of Department	..	B. A. Keen, D.Sc., F.Inst.P., F.R.S.
Scientific Staff		G. H. Cashen, M.Sc.
		P. C. Owen, B.Sc.
		H. L. Penman, M.Sc., Ph.D., A.Inst.P.
		E. W. Russell, M.A., Ph.D., A.I.B.A.E., F.Inst.P.
		R. K. Schofield, M.A., Ph.D., F.Inst.P.
Voluntary Workers	..	O. Talibuddin, B.Sc., M.Sc.
		A. J. da S. Texeira, Eng.Agron.
Assistant Staff ..	..	W. C. Game, Josephine Noond, J. Rolfe, Jessie A. J. Walker, Monica Waller

Chemistry Department—

Head of Department	..	E. M. Crowther, D.Sc., F.R.I.C.
Scientific Staff ..	..	P. W. Arnold, B.Sc.
		N. S. Bamji, M.Sc.
		Blanche Benzian, B.Sc., F.G.S.
		J. M. Bremner, B.Sc.
		W. E. Chambers, B.Sc., B.A.
		Elizabeth H. Cooke, B.Sc. (Hort.)
		G. W. Cooke, B.Sc., Ph.D., A.R.I.C.
		J. B. Hale, B.Sc., Ph.D., A.R.I.C.
		Signe G. Heintze, M.Phil.
		H. L. Nixon, B.A.
		R. G. Warren, B.Sc.
Voluntary Workers	..	H. F. Chu, B.Sc.
		B. C. Deb, M.Sc., D.Sc.
		E. M. de Mello, Ing.Agron.
		P. H. Nye, B.A., B.Sc.
Assistant Staff ..	..	E. Bird, A. H. Bowden, G. R. Burgess, W. N. Chapple, F. Cowland, Nellie Cressey, Paddy P. M. Gillow, Sheila M. Hills, Vera M. Hole, Mrs. Joan Judge, Brenda Milton, M. Roberts, F. J. Seabrook, Enid J. W. Smith, H. A. Smith, Sheila Stapleton, Margaret Wheatland

Soil Microbiology Department—

Head of Department ..	H. G. THORNTON, B.A., D.Sc., F.R.S.
Scientific Staff	LETTICE M. CRUMP, M.Sc., F.Z.S.
	P. C. T. JONES, B.Sc., A.R.C.S.
	JANINA KLECZKOWSKA, B.Sc., PH.D.
	JANE MEIKLEJOHN, PH.D. (On service)
	JANET E. MOLLISON, B.Sc., PH.D.
	P. S. NUTMAN, B.Sc., PH.D., A.R.Sc.
	DAGNY H. OXFORD, B.A.
	B. N. SINGH, B.Sc., PH.D.
Voluntary Workers ..	S. BHADURI, B.Sc.
	A. V. GARCIA, ENG.AGR.
Assistant Staff	JOAN CRAWLEY, MABEL DUNKLEY, VERA STOCK, ELEANOR M. WILLIAMS

Pedology Department—

Head of Department ..	A. MUIR, B.Sc., PH.D.

Botany Department—

Head of Department ..	WINIFRED E. BRENCHLEY, D.Sc. F.L.S.
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	KATHERINE WARINGTON, D.Sc.
Technical Assistant ..	EDITH RABL
Assistant Staff	BARBARA BISHOP, HEATHER PELLANT, PEGGY SAGE

Crop Physiology Section—

Head of Section	D. J. WATSON, M.A., PH.D.
Assistant	S. A. W. FRENCH

Statistical Department—

Head of Department ..	F. YATES, Sc.D.
Scientific Staff	F. J. ANSCOMBE, M.A.
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	ROSE O. CASHEN, PH.D.
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	O. KEMPTHORNE, M.A.
	IRENE MATHISON, M.PHIL.
	M. H. QUENOUILLE, B.A.
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Plant Pathology Department—

Head of Department ..	F. C. Bawden, M.A.
Scientific Staff	L. Broadbent, B.Sc.
	E. M. Crook, M.Sc., Ph.D., F.R.I.C.
	J. P. Doncaster, M.A.
	S. D. Garrett, M.A.
	Mary D. Glynne, D.Sc., F.L.S.
	P. H. Gregory, Ph.D.
	Brenda M. G. Hamlyn, B.Sc. (Hort.)
	B. Kassanis, B.Sc., Ph.D.
	A. Kleczkowski, M.D., Ph.D.
	Joan Moore, Ph.D.
	Florence M. Roberts, M.Sc., Ph.D.
	Frances M. L. Sheffield, D.Sc., F.L.S.
	Marion A. Watson, Ph.D.
Voluntary Worker ..	I. Macfarlane, B.Sc.
Glasshouse Superintendent	Margaret M. Browne
Technical Assistant ..	Lina Cunow
Assistant Staff	Gladys Custance, A. W. Halsey, June North, Ruth Walker

Biochemistry Section—

Head of Section	N. W. Pirie, M.A.
Scientific Staff	E. Margaret Holden, B.Sc.
	M. V. Tracey, M.A.
Voluntary Worker ..	J. Gregoire
Assistant Staff	Mollie Morton, Patricia Readhead

Entomology Department—

Head of Department ..	C. B. Williams, M.A., Sc.D.
Scientific Staff	H. F. Barnes, M.A., Ph.D.
	M. V. Brian, M.A.
	A. C. Evans, Ph.D.
	W. J. Guild, B.Sc.
	W. S. Richards, M.A., D.Phil.
Assistant Staff	Roger Harkness, Mrs. E. Koller, Mrs. S. Roberts (part-time)

Bee Department—

Head of Department ..	C. G. Butler, M.A., Ph.D.
Scientific Staff	P. S. Milne, B.Sc.
	Anne D. Synge, B.Sc.
Voluntary Worker ..	A. K. Wafa, B.Sc.
Assistant Staff	J. Ashton, J. Clifford, Queenie Sangster, Beryl Thorne

Insecticides Department—

Head of Department ..	F. Tattersfield, D.Sc., F.R.I.C.
Scientific Staff	Mrs. Eileen M. Gillham, B.Sc. (Hort.)
	K. Lord, B.A., A.R.I.C.
	A. H. McIntosh, B.Sc., A.R.I.C.
	C. Potter, D.Sc., Ph.D., D.I.C.
	Rosemary I. Stoker, B.Sc(Hort.)
	M. J. Way, B.A.
Assistant Staff	Poppy Alexander, Jean Holland, Barbara Hopkins, Mrs. Marjorie Piggott, M. Richards

Field Experiments—

Head of Section ..	H. V. Garner, M.A., B.Sc.
	M. J. Allen
	Myrtle Hughes (Clerical Assistant)
	B. Weston (Field Superintendent)

Farm Staff—

Farm Manager	J. R. Moffatt, B.Sc.(Agric.), N.D.A.
Assistant to Farm Manager	G. F. Cole
Experimental Assistants..	Betty Beaumont, Patricia Marsh
Office Staff	Pauline Cope (Secretary)
	S. Sonnenstein (Assistant)
Foreman	H. Currant
Farm Workers	T. Ablewhite, W. Barrett, P. Bird, J. H. Burslem, W. Cain, H. S. Chapman, D. Le Feuvre, A. Mills, F. Stokes, J. Underhill, H. A. Walford, L. Wright

Administrative and Clerical Staff—

Assistant Secretary ..	Constance K. Catton
Director's Private Secretary	Margaret A. Bushell
Senior Clerk	Mrs. O. Coleman
Senior Shorthand Typist	Mildred Ashford
Junior Office Staff	Stella Smith
	Gladys Spink

Library—

Librarian (full-time) ..	Isobel M. Anderson, M.A.
Librarian (part-time) ..	Helen Scherbatoff
Typist	Toni Sumner

Photography— .. .. V. Stansfield, F.R.P.S.

Maintenance Staff—

Storekeepers	A. Oggelsby, A. H. Bowden
Engineer	A. E. Hall
Caretakers, Cleaners, Gardeners and Nightwatchman	F. J. Hawkins, W. J. Smith, F. J. Stock, P. Bozier, Mrs. Bozier (part-time), Mrs. Smith (part-time), L. Allen, W. S. Fisher, G. E. Hooper, B. G. Burgess

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Scientific Staff—

Field Experiments ..	Capt. E. H. Gregory
Soil Microbiology Department	Jane Meiklejohn, Ph.D., W.A.A.F.
Bee Department ..	Pamela Schiele, B.A., W.R.N.S.

Assistant Staff—

Chemistry Department ..	Joan Chappin, V.A.D.
	David Henden, R.A.F.
	Eric Meadows, Army
	Jack Olver, Fleet Air Arm (missing)
	Louis Wiseman, Army
Physics Department ..	Harold King, R.A.F.
Insecticides Department	John Williams, R.A.F. (missing)
Entomology Department	Geraldine Cope, W.A.A.F.
	Anita King, W.A.A.F.
	Ian Long, R.A.F.
Field Experiments ..	Gordon Weston, Army Medical Service

In addition to the above, certain members of the Scientific Staff were seconded for various military and civil duties.

Members of the Scientific Staff who left between January, 1939, and December, 1945 :

Chemistry Department ..	G. Nagelschmidt, D.Phil.
	A. H. Bunting, M.Sc., D.Phil.
Soil Microbiology Department	D. Ward Cutler, M.A., F.L.S., head of Department, died 1941
	Hugh Nicol, Ph.D., F.R.I.C. (transferred to Imperial Bureau of Soil Science)
Crop Physiology Section	R. S. de Ropp, B.Sc., Ph.D.
Statistics Department ..	W. G. Cochran, M.A.
	D. J. Finney, M.A.
Plant Pathology Department	J. Henderson Smith, M.B., Ch.B., B.A., head of Department, resigned 1940
	A. G. Walker, B.Sc.
	Mrs. Wendy M. Dion, B.Sc., Ph.D.
	Mrs. E. J. Bradley, B.Sc.

Biochemistry Section ..	J. S. D. Bacon, M.A.
Entomology Department ..	H. C. Gough, B.Sc., Ph.D.
	G. F. Cockbill, B.Sc.
Bee Department	Pamela Schiele, B.Sc.
	A. C. Fabergé, Ph.D.
	E. P. Jeffree, B.Sc.
Insecticides Department ..	J. T. Martin, B.Sc., Ph.D., D.Sc., F.R.I.C.
	S. H. Harper, Ph.D., D.Sc., A.R.C.S., D.I.C.
Library	Miss Mary S. Aslin
Fermentation Department ..	E. H. Richards, B.Sc., F.R.I.C., head of Department, died 1939
	N. W. Barritt, M.A.
Field Demonstrator	E. H. Gregory

The following spent varying periods as voluntary workers at Rothamsted during 1939-1945 :

(1) From the British Commonwealth

Australia : A. L. C. Davidson. Miss H. N. Turner

ERRATUM

P. A. Loizides (Cyprus) has been inadvertently included in the list of workers from foreign countries.

(2) From Foreign Countries

Belgium : P. Manil, L. Lebacq
Bulgaria : P. Boyanoff, J. P. Stoitchkoff, A. Christoff
Chile : R. A. Aguirre
China : H. K. Chen, C. I. Shen, Y. Hwang, M. J. Lan
Cyprus : P. A. Loizides
Czechoslovakia : J. Klaus, D. Rozsnyai, B. Kvicala
France : I. Farbman
Greece : G. Polychroniades, A. Sismanidis
Holland : M. F. Faure, A. H. Justensen
Hungary : B. Ripp
Poland : V. Balcerek, Mrs. L. Kapica, B. Monic, S. Kirkov, Mrs. M. Boczkowska
Spain : A. Gaspar
United States of America : J. Deal
Yugoslavia : S. P. Saric

(3) From the British Isles

D. G. Arnott, M. Barrowcliff, M. Bernal, F. Billett, S. de Blank, S. Brightwell, Miss J. K. Bridges, F. J. Burger, L. F. Burroughs, Miss M. K. Burton, Miss P. M. Carlisle, Miss D. E. Clarke, E. H. Cooper, J. L. Crammer, W. A. L. David, N. Dugdale, J. Edelman, H. T. Fawns, Miss P. E. Ferguson, Miss E. Glenn, D. W. Goodall, E. R. Goodliffe, R. A. Green, R. Greene Kelly, Miss E.

G. Grey, G. T. Halsey, M. A. G. Hanschell, Miss C. Harstein, Miss J. E. Heriot, D. J. Higgons, K. A. Hyde, A. Jefferiss, P. Jones, H. H. le Riche, P. H. Le Mare, R. N. P. Luddington, E. W. Maslen-Jones, H. W. Matthews, G. E. Mattingley, E. J. Meyer, S. Michaelson, Miss J. P. V. Morgan, Miss B. L. Moss, A. Neighbour, S. R. Nutman, Miss E. M. Oakley, H. Palca, Miss C. M. Palmer, Miss D. R. Parkinson, W. Plant, Miss R. Porter, Mrs. Potter, Miss M. M. Preston, E. C. R. Reeve, I. G. Reid, Miss J. E. Rippon, Miss H. Rogers, Miss J. Scott, W. J. P. Smyly, J. E. Stuart, H. J. Tovey, Miss E. M. Tuke, Miss E. M. Turner, T. W. Walker, S. C. Wallwork, J. Watson, Miss N. J. Watts, A. Wesley, E. J. Williams, Miss J. Williams, Miss Winfield, B. Woolf.

Woburn Experimental Station
1939-1945

Director	W. G. Ogg, M.A., Ph.D.
Assistant Director ..	H. H. Mann, D.Sc., F.R.I.C. (Kaisar-i-Hind Gold Medal)
Chemist	T. W. Barnes, M.Sc., F.R.I.C.
Assistants for Experimental Work	D. Wood (till 1940) G. Pearce (from 1940) W. M. Sturges

Farm Staff—

Foreman and Stockman..	W. A. McCallum
Farm Workers	W. L. Angell, H. J. Coleman (till 1943), C. E. Horn, S. B. Horn, R. Mallone, W. McCallum, Jr. (till 1941), D. A. Neale, R. Pearce (till 1941), A. Sibley, G. Tyler

Imperial College of Science and Technology
(Research Institute of Plant Physiology)

Director	F. G. Gregory, D.Sc., F.R.S.
Head of Department ..	F. J. Richards, M.Sc.
	H. K. Porter, D.Sc.
	O. V. S. Heath, Ph.D.
	M. Holdsworth, Ph.D.
	W. W. Schwabe, B.Sc.
	R. V. Martin

Agricultural Research Council Unit of Soil Metabolism

Head of Unit	J. H. Quastel, D.Sc., F.R.S.
Scientific Staff ..	P. J. G. Mann, B.Sc., Ph.D.
	H. Lees, B.Sc., Ph.D., A.R.I.C.
	D. M. Webley, B.Sc., Ph.D.
	G. M. Ellinger, B.Sc.
Assistant ..	W. J. Redmond

The Imperial Bureau of Soil Science

Director	G. V. Jacks, M.A., B.Sc.
Consultant Director ..	W. G. Ogg, M.A., Ph.D.
Assistants	H. Nicol, Ph.D. Helen Scherbatoff Mrs. R. Nicol
Clerks	Cynthia Horn, Rita Perry

The Bureau is one of ten Imperial Agricultural Bureaux, and was established at Rothamsted in 1929. Administratively and financially the Bureau is distinct from the Station, but the closest collaboration exists in the work of the two. The Director of the Station is *ex officio* Consultant Director of the Soil Bureau.

The function of the Bureau is to assist workers in soil science throughout the Empire by providing technical information, by promoting contact between them, and by rendering any technical assistance possible when they are in this country. A quarterly abstract journal *Soils and Fertilizers*, covering the literature of soil science, fertilisers and the culture of field crops throughout the world is published, together with occasional monographs—*Technical Communications*—on subjects of general interest. To facilitate its work, the Bureau seeks to be well informed as to the personnel engaged in soil work in the Empire and the problems on which they are engaged. Each Government has been requested to nominate one of its staff as Official Correspondent to the Bureau, who acts as liaison officer in Bureau matters and assists in the collection and distribution of information. The issue of technical information is usually free to all workers in soil science who ask the assistance of the Bureau.

INTRODUCTION

The Rothamsted Experimental Station was founded in 1843 by the late Sir J. B. Lawes, with whom was associated Sir J. H. Gilbert for a period of nearly 60 years. Lawes died in 1900 and Gilbert in 1901 ; they were succeeded by Sir A. D. Hall from 1902 to 1912, and by Sir E. J. Russell from 1912 to 1943 when the present Director, Dr. W. G. Ogg, was appointed.

For many years the work was maintained entirely at the expense of Sir J. B. Lawes, at first by direct payment, and from 1889 onwards out of the income derived from the endowment fund of £100,000 given by him to the Lawes Agricultural Trust. In 1904 the Society for Extending the Rothamsted Experiments was instituted for the purpose of providing funds for expansion. In 1906, Mr. J. F. Mason built the Bacteriological Laboratory ; in 1907, the Goldsmiths' Company generously provided a further endowment of £10,000, the income of which—since augmented by the Company—is devoted to the investigation of the soil. In 1911, the Development Commissioners made their first grant to the Station. Since then, Government grants have been made annually, and at the present time over 90 per cent. of the necessary funds is provided from Government sources—mainly by the Ministry of Agriculture and the Agricultural Research Council.

The main block of laboratories was opened in 1919 ; another block was erected in 1924 for plant pathology by a grant provided by the Ministry of Agriculture out of the Development Fund ; and Red Gables, the house adjoining the laboratories on the north side, was converted into an Administration Building to hold the Imperial Soil Bureau, Staff Common Room, and Conference Room.

Large glasshouses, including special insect-proof houses for virus studies, were added in 1926, 1928, and 1931 by aid of generous grants from the Rockefeller Foundation, the Empire Marketing Board and the Ministry of Agriculture. A new large range of houses, some of which are insect-proof, was erected in 1935 for plant-pathology investigations.

A large new South Wing was completed in 1940, and the old chemical laboratories were reconstructed. These extensions and reconstructions have provided excellent accommodation for the Chemistry, Biochemistry, Physics and Microbiology Departments ; in addition a fine range of pot-culture houses was built. A new laboratory has also been built and equipped for workers from the Imperial College of Science and Technology.

The Rothamsted Home Farm of 250 acres came under the management of Sir John Lawes in 1834, the experimental fields being worked from the farm buildings at the Manor House. In 1913 the first range of farm buildings and cottages was erected on the site of the present buildings. These were considerably enlarged in 1930-32 and equipped for electric light and power. Further additions were made in 1939-41, and the electricity supply has now been extended to these newer buildings.

From 1926 onwards, new and greatly improved methods of field experimentation were adopted on all but the classical plots, which remained essentially unchanged. In 1945 the number of plots reached 1722, the highest in the history of Rothamsted.

The non-experimental part of the farm was re-organised in 1928 to meet prevailing economic conditions, much of the land being laid down to permanent grass, and cattle and sheep were introduced. In 1939 this policy was reversed, ley farming was introduced, and the arable acreage was increased to meet war-time conditions.

The Library is steadily growing and now contains over 30,000 volumes dealing with agriculture and related subjects. Extra accommodation has become an urgent problem. New accessions can now be housed in the main library only by removing other books to improvised store rooms which also are rapidly approaching repletion. Miss M. S. Aslin, who had been Librarian since 1919 retired in 1942, and was succeeded in 1945 by Miss I. M. Anderson, M.A. The catalogue of old books on agriculture in the possession of the Library was brought up to date and reprinted in 1940. Further additions to the collection of old books are made whenever opportunity occurs.

The extension of the experiments to various outside centres in Great Britain, begun in 1921, has proved so advantageous that it has been developed. Not only is useful information spread among farmers, but the Station gains considerably by this closer association with the Universities and Advisory Services. As part of this extension, the Station took over in 1926 the Woburn Experimental Farm. We were thus able to make experiments simultaneously on the light land at Woburn and the heavy land at Rothamsted.

In May 1934, the negotiations for the purchase of the farm and some adjoining parts of the Rothamsted Estate were completed. The Rothamsted Trustees now own the site of the laboratories, the experimental and ordinary farm fields, Knott Wood, the Manor House and grounds, the farm manager's house, and eight cottages. The total area is 527 acres. The purchase price was £35,000, all of which was raised by public subscription. Generous contributions were received from Sir Robert McDougall and others, and a highly encouraging feature of the appeal was the number of subscriptions received from farmers, village school teachers, and from overseas sources.

The activities of Rothamsted, however, are not confined to the British Isles, but are gradually spreading out to the Empire and other countries. The Station regularly participates in work for the solution of agricultural problems of great importance to the Empire.

The Station offers research facilities for post-graduate students, but unfortunately the number of additional workers that can be accommodated is at present strictly limited by lack of laboratory space.

The Imperial Bureau of Soil Science, one of the ten Imperial Agricultural Bureaux set up to act as clearing centres of information on agricultural science, has been located at Rothamsted since its establishment in 1929.

REPORT BY THE DIRECTOR

Because of the war no annual report has been printed since 1938, and the present report covers the years 1939 to 1945 inclusive. It differs in certain respects from the pre-war annual reports. As in the case of the account published at the time of the Centenary, the work of each department is described in some detail by its head. There is a good deal to be said for describing in this way the work of a specialist institution engaged largely on the more fundamental problems. It should be made abundantly clear, however, that the work at Rothamsted is not conducted in a series of water-tight compartments. There is consultation and collaboration between the departments from the preparation of the programme to the writing up of the results, and many of the investigations or parts of them are carried out jointly by members of different departments. Contact is maintained formally by meetings of a Staff Council and by scientific discussions held about every three weeks, but the informal contacts, when the staff meet daily for tea, are even more important.

The war-time report follows the pre-war abridged reports in omitting the tables giving the detailed results of experiments. The figures for any particular experiments may be obtained on application to the Secretary.

Acknowledgement is made to Mr. G. V. Jacks for editing this report.

In spite of the proximity to London, Rothamsted suffered no damage from enemy action during the war. Incendiary bombs were dropped on two occasions, one landing on the roof of the laboratories and several others about the premises and in the Director's garden, but they were dealt with by the very efficient fire-watching service organised by the staff from its members. On a few other occasions, strings of high-explosive bombs were dropped on the Common in front of the building and on the farm, but no one was injured and no damage was done either to buildings or crops. Dr. R. K. Schofield was in charge of the A.R.P. work assisted by Mr. D. J. Finney, Dr. J. T. Martin and Mr. R. G. Warren; Dr. Winifred E. Brenchley also took an active part, especially with regard to first-aid and catering.

Accommodation was provided for workers evacuated from the Department of Biometry and Eugenics of London University, the British Leather Manufacturers' Research Association, Diagram Films Ltd., and the Public Health Department of the Ministry of Health.

The Centenary Celebrations

The Centenary of Rothamsted was celebrated on 21st July, 1943. Owing to the war and the difficulties of travelling, the celebrations were on a much smaller scale than they would otherwise have been. Nevertheless there were nearly 300 guests and 25 countries, including the Dominions, were officially represented. Amongst those present were Mr. R. S. Hudson, the Minister of Agriculture, the Duke of Norfolk, Joint Parliamentary Secretary to the Ministry of Agriculture, the Marquess and Marchioness of Salisbury, the

Viscount and Viscountess Bledisloe, and Sir Henry Dale, President of the Royal Society.

In the morning the guests were taken in small parties round the laboratories and had an opportunity of inspecting the new south block, the remodelled sections of the main block, and the new pot-culture houses.

After a luncheon in the Public Hall, addresses were given by the Earl of Radnor, Chairman of the Lawes Trust Committee, Mr. R. S. Hudson and Sir John Russell.

Many messages of congratulation were received from overseas and from well-wishers in this country.

In the afternoon the guests were taken round the farm and inspected some of the more important experiments including the 100th successive wheat crop on the Broadbalk field.

Parallel meetings to commemorate the Centenary of Rothamsted were held in Moscow by the agricultural scientists of the U.S.S.R., in Cincinnati by the Soil Science Society of America, and commendations of Rothamsted's work were made at meetings in Spain and Portugal.

Retirement of Sir John Russell

On 30th September, 1943, Sir John Russell retired from the directorship of Rothamsted. Dr. W. G. Ogg, formerly director of the Macaulay Institute for Soil Research, Aberdeen, was invited to succeed him.

Sir John joined the Rothamsted staff in 1907 and was appointed director when Sir Daniel Hall left in 1912. During his long tenure of office, Sir John completely reorganised and greatly expanded the Station, and, what was still more important, gathered round him a first-class staff. He built up what is now one of the finest agricultural libraries in the world, and raised large sums of money for the rebuilding of the laboratories, pot-culture houses and farm buildings and for the purchase of Rothamsted farm and Manor House. In this summary it is impossible to deal adequately with Sir John's great services to Rothamsted and to the agriculture of the Empire. He travelled widely and did much to make the work of the Station known in other countries. Besides serving on numerous committees set up by the Ministry of Agriculture, the Agricultural Research Council and the Colonial Office, he took an active part in the work of the Allied Post-War Requirements Bureau and UNRRA. During the war he also served part-time with the Soviet Relations Division of the Ministry of Information which entailed making extensive lecture tours in many parts of the country.

When he retired the staff and former workers presented him with his portrait painted by Francis E. Hodge.

Improvements to Laboratories and Farm Buildings

In 1938 a Centenary Fund was inaugurated for the purpose of reconstructing some of the old laboratories and erecting new ones: also for setting up pot-culture houses and extending and improving the farm buildings. There was a ready and generous response from many friends and supporters of Rothamsted and, had it not been

for the war, it seems certain that the target of £125,000 would have been reached. With the coming of the war, however, the appeal was discontinued, and the Rothamsted Centenary Fund was closed in 1939 when nearly £67,000 had been received or promised. With this sum, which included £15,000 from the Ministry of Agriculture for the South Wing and for spectrographic equipment, excellent accommodation has been provided for the departments of Chemistry, Biochemistry, Physics and Microbiology, pot-culture houses have been built and farm buildings reconstructed. The latter are now ideal for their purpose, having modern electrical equipment and spacious barns in which the experimental crops can be stored and threshed during the winter months. Unfortunately the projects for improving the accommodation of other scientific departments, re-housing our unique agricultural library, and providing administrative offices and an Assembly Hall, have had to be postponed. Lack of accommodation is hindering the development of the Station's work and has led to the necessity of refusing to accept some of the voluntary workers from other countries. It is, in fact, proving difficult to find room for workers training for our own and the Colonial agricultural research services.

There is also an urgent need for providing more farm cottages, improving the lay-out at the back and front of the laboratories, and re-making the road to the farm.

The Work of the Station in War-time

As was to be expected the war had a marked effect on the work of Rothamsted. The field work of the classical and the more important of the other experiments, particularly the long-term ones, was continued. Much of the laboratory work had to be allowed to fall into arrears and many investigations had to be postponed in order that *ad hoc* problems, immediately connected with increased food production, might be undertaken.

Most members of the staff were engaged in various forms of war work and consequently were reserved, nevertheless 14 entered H.M. Forces and we regret to record that two—Jack Olver (Fleet Air Arm), assistant in the Chemistry Department, and John Williams (R.A.F.), assistant in the Insecticides Department—were reported missing. A few members were seconded for scientific work elsewhere, but most of the staff carried on their war duties at Rothamsted.

Between 1938 and 1945 the total number of workers, including voluntary workers, assistant staff, farm workers and the Woburn staff, increased from 143 to 219.

Among those who left us were Dr. J. Henderson Smith, who resigned in 1940 after 21 years at Rothamsted, the last eight as head of the Plant Pathology Department, and Miss Mary S. Aslin, who resigned in 1942 after 23 years' service as librarian.

It is with regret that we record the death during the early war years of two heads of departments—Mr. E. H. Richards, head of the Fermentation Department, who died in 1939, and Mr. D. Ward Cutler, head of the General Microbiology Department, who died in 1941. Both of these workers had been on the staff since 1919.

In 1940 an Agricultural Research Council Unit dealing with

soil metabolism was set up at Rothamsted under Dr. J. H. Quastel, F.R.S. This Unit was transferred to the University College of South Wales, Cardiff, at the end of 1945.

The Bee Section has been made a separate department recently under Dr. Butler, and a new Pedology Department has been established, in 1945, under Dr. A. Muir. Arrangements have also been completed for the setting up of a separate Biochemical Department, and for the appointment of a Colonial Soils Adviser.

The following is a brief review of the main lines of work : more detailed accounts are given by the heads of the various departments.

Soils and crop nutrition

Much of the soil work consisted of short-term investigations which could be regarded as " operational research " in the food-production campaign. These investigations, however, have had more than a short-term value for they have supplied much information which will be of value in long-range soil-fertility investigations. Amongst the problems set us by the war were : how to maintain or increase production and at the same time practise a rigid economy in the use of fertilisers, and how to handle to the best advantage the large area of old pasture land which had to be broken up.

A statistical examination by E. M. Crowther and F. Yates of the results of all the recorded field experiments made during this century in Britain and various European countries revealed the average fertiliser needs of different farm crops. This threw light on problems of fertiliser imports and showed how the supplies could be most efficiently distributed. It was of great value in formulating the war-time fertiliser policy.

As in the past, much of the soil-fertility work was a combination of field experiments and laboratory investigations. In addition to those on the Rothamsted and Woburn farms, many experiments were carried out on commercial farms in different parts of the country.

A good many of the special war-time investigations were done on behalf of the Agricultural Research Council, the Ministry of Agriculture and the Ministry of Supply, and in collaboration with the staffs of other research institutes and with the advisory chemists.

The sugar-beet manuring trials begun in 1933 were continued, and it was clearly shown that the outstanding requirements of this crop are nitrogen and sodium. It was demonstrated that sodium acts as a direct plant food and the application of 5 cwt. of common salt produced, on an average, about 5 cwt. of extra sugar. As a result of these experiments the manuring of sugar beet has been put on a more satisfactory basis. As well as throwing light on the manuring of sugar beet these experiments have proved useful in developing and improving methods of soil analysis for advisory work.

A considerable amount of work done on the manuring of flax showed that this crop is relatively unresponsive to fertilisers and should be manured like barley.

Investigations on organic manures have also been a feature of the war-time programme, and an attempt has been made to assess the physical as well as the manurial effects. The materials studied included farmyard manure, sewage sludge, straw and various

composts. Stacked young bracken gave excellent results. Sewage sludges proved much less effective than good farmyard manure or bracken compost and supplied little beyond nitrogen and phosphate. Promising results were obtained from composts of straw and sewage sludge. An investigation on waste leather showed that it can be converted into an active nitrogen fertiliser by de-tanning, but the process has not yet reached a commercial scale.

Another major project has been the study of phosphatic fertilisers and particular attention has been given to questions of availability and to the problem of phosphate fixation. It is perhaps not generally realised that of the phosphate applied as fertiliser not more than 20 per cent. as a rule is recovered in the crops. A new phosphate fertiliser—silico phosphate—was developed in collaboration with the Building Research Station, and was found to compare very favourably with superphosphate for swedes and for re-seeding in wetter areas.

Fertiliser placement provides an obvious economy, particularly in the use of phosphate, and the process is now well established for cereals and is being tested for other crops.

Work on trace elements has been carried out in the departments of botany, chemistry and biochemistry and considerable progress has been made in the study of manganese deficiency. Deficiencies of manganese, boron, magnesium and potassium can now be recognised and distinguished from each other and from chlorosis due to virus and fungus diseases. The trace elements contained in Chilean nitrate were studied for several years by Dr. Brenchley and Dr. Warington, boron being the most important. Iodine gave negative results, but there were indications that molybdenum improved the growth of lettuces, and this element is being studied more intensively with various crops. The toxic effects of larger amounts of molybdenum and other trace elements are also being investigated.

Soil-moisture and cultivation studies

An examination of the daily readings of the Rothamsted drain gauges for the period 1871 to 1940 and of the continuous records taken since 1925 has yielded important information about the rate of evaporation from bare soil, and laboratory experiments have helped to elucidate the physics of the process. The transpiration of short grass continuously supplied with water from a controlled water table has been measured during two summers and its dependence on the supply of energy from solar radiation established. It is proposed to make the same measurements for tall crops. This technique should provide more precise indications of the optimum quantities of water to be supplied in irrigation work.

The study of the manner in which water is retained in soil has been continued, and progress made in devising means for measuring *in situ* the suction (or pF) of the soil moisture. A method has also been devised for obtaining the volumes occupied by solids, water and air in soil clods. Measurements have been made of the fraction of soil particles of effective diameter less than 0.1μ, and a physico-chemical study of the buffer action of a number of pure polysaccharides has paved the way for an attack on the complex chemistry of the organic matter of the soil.

The results of soil-cultivation experiments on different soils and in different seasons are consistent with the laboratory and drain-gauge work and with comparable experiments in the United States and elsewhere. They demonstrate the depression of crop yield due to weed competition, but show that inter-row cultivation does not reduce direct evaporation from the soil.

Nodule bacteria and other soil micro-organisms

Some strains of nodule bacteria, particularly on clover, produce nodules practically ineffective in fixing nitrogen. These appear to be characteristic of poor pastures in hilly districts in the west and north of Britain, and the possibility is being investigated of improving the clover content of such pastures by inoculation with effective strains of nodule bacteria. The problem is by no means simple, however, for effective strains are liable to mutate and become ineffective on certain soils : moreover, acute competition has been found to take place between the nodule bacteria introduced by inoculation and those already present in the soil. The cause of ineffectiveness appears to be the inability of certain strains to grow strongly on the host-plant tissues or to survive therein long enough to fix appreciable amounts of nitrogen. The behaviour of the nodule bacteria is controlled by genes in the host plant as well as by the nature of the bacterial strain.

A study of the chemical nature of the bacterial secretions which cause deformation of root hairs by nodule organisms eventually led to the discovery of the high toxicity to many dicotyledonous plants of 2 : 4 dichlorphenoxyacetic acid. This and a closely related compound are now in practical use in this country and in America as differential weed killers for use in cereal crops.

Studies on the general micropopulation of field soils have been facilitated by the development of a new direct method of counting bacterial cells and of estimating the quantity of mycelium in soil by direct microscopical observation. A greatly improved technique for estimating numbers of protozoa in soil has also been devised. By the use of these improved techniques several groups of micro-organisms, formerly thought to be very rare or even adventitious in soil, have been found to be true and widely distributed soil inhabitants. These include giant rhizopods, acrasieae and myxobacteria. Of special interest are the myxobacteria which secrete compounds that destroy and dissolve gram-negative as well as gram-positive bacteria. Most of the former group are not attacked by penicillin. Soil protozoa and acrasieae have been found to be very selective in their bacterial food so that they are capable of altering the quality as well as the total size of the soil bacterial flora.

Virus diseases of plants

Plant-pathological work has increased greatly since 1939 and particular attention has been given to the diseases of potatoes, sugar beet and cereals. As far as possible all the lines of work both with viruses and fungi that were being studied in 1939 have been continued, and a good deal of advisory work has also been undertaken.

The study of viruses has been facilitated by the acquisition of an ultra-centrifuge and an electron microscope. New viruses have been

isolated and identified as crystalline nucleoproteins, and studies have been made of their physical, chemical and serological properties. The serological work has led to the development of a rapid method of diagnosis for some of the commoner virus diseases. Wide variations in the size and shape of tobacco-mosaic virus have been detected and the conditions responsible for the variations have been determined. The shape of the virus particles has been found to account for their serological behaviour. The factors responsible for flagellar and somatic-type serological behaviour have been elucidated. The manner in which viruses are held in infected tissues has been studied, and it has been found that infected plants contain much more virus than was previously suspected. The work has included studies of the origin and significance of intra-cellular inclusions, new types of which have been found in infected plants and new insects have been identified as vectors. The intricate relationships between viruses and their vectors have been studied, and in the field special attention is being given to the factors which affect the spread of virus diseases particularly in potato and sugar-beet crops. Annual surveys of the insects and virus diseases of these two crops have been made and much information has been obtained on the effects of weather on the insect vectors, the relative importance of different species of insect in causing spread, the distance over which spread occurs and the important sources of infection. A book on Plant Viruses and Virus Diseases was published by F. C. Bawden in 1939 (second edition, 1943).

Biochemical work on normal and virus-infected leaves has been in progress since 1940 and has included studies of the conditions governing the release of normal protein from the leaf fibre. Use has been made of methods involving fine grinding and enzymatic disintegration. Work has also been done on plant proteases and on pectase. Extraction and fractionation of tobacco-mosaic, tomato bushy-stunt and the tobacco-necrosis viruses were carried out in the Biochemical Section.

Fungus diseases

Increased attention has been given to field work on fungus diseases. Surveys of commercial crops in many districts have shown the importance of Eyespot of wheat (*Cercosporella herpotrichoides*), and many experiments have been made to ascertain the conditions favouring this disease and to devise control measures. A survey of the causes of wastage in stored potatoes showed that *Phytophthora infestans* was the main cause but also revealed a previously unsuspected cause *Fusarium avenaceum*. Studies have been made of the environmental conditions affecting the survival of soil-borne fungi, their ability to cause infection and their survival in the absence of susceptible crops. Among the fungi studied were *Ophiobolus graminis*, *Fusarium culmorum*, *Plasmodiophora brassicae*, *Rhizoctonia solani* and *Verticillium albo-atrum*. A book on Root Disease Fungi by S. D. Garrett was published in 1944.

Studies of earthworms, slugs and various insects

Work in the Entomology Department can roughly be grouped into three divisions, a study of the causes of insect outbreaks, secondly work on particular pests—not necessarily insects—such as

slugs, wireworms and gall midges, to study their biology and control, and thirdly an investigation on earthworms and their relation to soil formation and fertility. The last mentioned was started about three years ago, and some 15 species of earthworms have been found on Rothamsted farm in varying relative abundance according to the type of soil and cultivation. A new species has been discovered. Each species has its own particular life cycle and habits, and each will no doubt have its own specific effect on soil conditions. It is already apparent that it is neither desirable nor justifiable to speak in general terms of the effect of " earthworms " any more than of the effect of "insects." Some go deeply into the soil, others live near the surface : some make worm casts above the ground, others do not. Every effort is being made to put the work on a sound basis both biologically and statistically.

Observations on the life cycle and abundance of slugs have now been going on for a considerable period on a statistical basis. The various species are being identified and their habits and ecological relationships studied. It has been found that very small changes in the environmental conditions of gardens make big differences in the total slug population and particularly in the relative numbers of the component species.

A study which has been going on for 20 years of wheat midges on Broadbalk has shown a relationship between the percentage of grain attacked and the annual yield. There is also a correlation between the date of emergence of the wheat midge and the harvesting date. The study of insect outbreaks is really a study of changes of insect numbers in a locality, as outbreaks are only a sudden increase in numbers beyond the danger point. This increase can be brought about by weather conditions favourable to the pest or unfavourable to its enemies, or, alternatively, by a deliberate or accidental movement into the area from outside—in other words by migration or by drift. Some progress has been made in all these branches, and C. B. Williams has obtained a formula for forecasting the general level of insect abundance at Rothamsted for any one month from the weather conditions of the previous three months. It has been shown that under the climatic conditions at Rothamsted, temperature is the most important factor in the winter months and rainfall in the summer months in determining insect abundance.

The control of insect pests

During the period under review there was naturally a concentration of effort on problems connected with the war, and later on the application of recently discovered insecticides to agriculture and horticulture. It was possible, however, to carry on some of the pre-war programme, and the search for new insect test subjects for evaluating insecticides was continued and also studies on the effect of environment on insect resistance. Extensive researches have been carried out on insecticides derived from plants used by the natives of tropical countries as fish poisons. Species of Derris, Lonchocarpus, Tephrosia and many others have been examined. The work on derris root included its evaluation by chemical means and the investigation of the effect of its several constituents on each other's insecticidal value. Six active principles, of which

rotenone was the most potent, were isolated, and S. H. Harper elucidated the structure of elliptone and malaccol and discovered a compound with an *iso*-flavone structure which he suggested might well be a precursor of the several compounds found in Derris and Lonchocarpus.

Much work has also been done on the powerful insecticide pyrethrum. In the years 1939-42 pyrethrum flowers and their extracts were of importance for food preservation and the control of insect pests such as the mosquito and the body louse. An important drawback was the dermatitis caused by pyrethrum preparations in susceptible people. J. T. Martin, himself a susceptible subject, studied this problem and showed by personal experiments that the pyrethrins themselves were not responsible, and further work has since been done on sorption methods for preparing concentrates relatively free from this trouble. Biological methods were worked out for the evaluation of the pyrethrum heavy-oil insecticides extensively used for the protection of stored food. Another piece of work dealt with the stability of certain pyrethrum preparations for prospective use as mosquito repellants. Methods of preparing standard pyrethrum-in-oil preparations were devised, and methods of chemical analysis of similar commercial preparations worked out and it was found that the biological and chemical techniques gave results which agreed fairly closely.

Attention has been concentrated recently on the biological assessment of stomach-poison insecticides: the susceptibility of insects as affected by strain, species, age and environmental factors: and on the investigation of certain potent synthetic compounds such as D.D.T. developed largely for war needs in order to ascertain their usefulness in the agricultural and horticultural field. Field-scale trials in conjunction with the Plant Pathological Laboratory of the Ministry of Agriculture were carried out with D.D.T. at several centres. It was shown that cabbage caterpillars and such pests as mustard beetle were completely controlled. Other pests were controlled to varying extents, but red spider and, to a less degree, certain aphides were resistant. Laboratory tests were also carried out on a wide range of insects and such points as potency and degree of persistence under weathering were studied. Work is in progress to test the effect of particle size and shape upon the toxicity of D.D.T., and a dipping technique for determining the insecticidal value of various types of preparations is being worked out. Account was taken of the effect of D.D.T. on beneficial insects and, jointly with the Bee Department, the toxic action on bees, both by contact and as a stomach poison, was studied. The results obtained so far indicate that the danger is less serious than was anticipated. The possibility of harmful effects on the plants themselves was also examined, and it was shown that cucumbers and vegetable marrow suffered some damage.

A prolonged research in which the various analogues of D.D.T. were compared showed that, molecule for molecule, D.D.T. was more toxic than its analogues but that the slopes of the respective regression lines were very different. An explanation of this is now being sought.

THE DISEASES OF BEES

The researches of the Bee Department fall into three categories —(1) work on the physiology, behaviour and morphology of the healthy bee; (2) investigations on the pollination of fruit and seed crops; (3) researches on the diseases of adult bees and their brood. An advisory service is also maintained and some 4,000 to 5,000 samples of bees and combs suspected of disease are examined every year free of charge.

The spread of the disease known as foul brood had been viewed with some concern during the years preceding 1939. On the outbreak of war it was feared that the spread might be accelerated by the call-up of beekeepers and the consequent neglect of their colonies. The Rothamsted Bee Research Advisory Committee therefore drew up a plan for the control of foul brood by means of legislation which eventually became law as the Foul Brood Disease of Bees Order, 1942. It provides for the inspection of any premises on which bees are kept, within three miles of a suspected outbreak of foul brood, and for the compulsory destruction of all infected colonies in the area. The application of the Order has shown that in many areas the incidence of foul brood was in fact much higher than had been suspected and that the introduction of legislation was necessary. The returns for 1945 justify the hope that the cumulative effects of widespread neglect of the foul-brood problem prior to 1942 are now being overcome and that continued vigilance will result in a steady decrease in the incidence of disease in future years.

The use of sulphonamides fed in sugar syrup to colonies infected with American foul brood, first reported to the Department by Mr. C. A. Ekins of Surrey, has given highly promising results, and further work is in progress with a view to obtaining a method of treatment as an alternative to destruction of colonies infected with either American or European foul brood.

Another activity of the department is a survey of adult-bee diseases. During the 1914-18 war Isle of Wight disease caused losses estimated at 90 per cent. of the bee population of Britain. The situation was restored by a re-stocking scheme, by the discovery of the causal agent of the disease and by the subsequent development of control measures, though the trouble, better known now as Acarine disease, continued to occur in many districts. Surveys carried out in 1941-42 and 1943-44 were designed to determine the incidence and distribution of Acarine and other adult-bee diseases and to reveal, in time to prevent the possibility of disaster on the 1914-18 scale, any tendency for a disease or diseases to assume epidemic proportions. Fortunately there was no evidence of any serious situation arising and, as regards Acarine disease, the position showed some signs of improvement in the interval between the surveys.

THE APPLICATION OF STATISTICAL METHODS

On account of the great demand for statistical assistance in connection with a wide variety of war-time activities including military operations, new researches in statistical theory and method had necessarily to be curtailed. Apart from the war, however, the trend was in the direction of the fuller development of already

established principles, for each type of problem requires its own specialised approach. There had in the past been a tendency to over-generalised treatment, and insufficient account was taken of the complexities to which each problem is subject. Many improvements on method and refinements of technique have been introduced, however.

One of the most valuable contributions of the statistician is in the design of experiments and the planning of experimental programmes. It is now becoming more generally recognised that the modern type of factorial design can greatly increase the information obtainable. If all combinations of several different sets of treatments or " factors " are included in one factorial experiment a number of interrelated aspects of the same problem can be studied simultaneously with considerable economy of space and with the advantage that the dependence of one treatment on the intensity of another can be determined. The advantages that come from being able to study variable material quantitatively, from asking several questions at a time and from obtaining unbiased measures of the effects of treatment and of experimental error are obviously invaluable in biological work.

Various references have already been made to the application of statistical methods in the work of the Station. Not only are practically all the field experiments of Rothamsted and its associated centres dealt with, but also many of the laboratory and other experiments. Numerous enquiries are also received from other institutions both in this country and overseas.

One of the most valuable contributions of the Statistical Department has been the preparation of critical quantitative reviews of all the experimental data on certain problems. An example is the summary of fertiliser trials already mentioned. Another instance is the investigation of the effect of changes in level of feeding of dairy cows on milk production. This review showed that overstringent rationing resulting from shortage of foods might result in a serious reduction in milk supply without any equivalent saving in food.

An investigation has just been begun to compare the economic value to the livestock farmer of temporary leys as compared with old grass. This forms only a small part of a much more general problem which is, broadly, the study of the agronomic and economic value of ley farming compared with other farming systems. This complex problem is naturally the affair of many other research stations besides Rothamsted.

During the war the importance has been realised of having accurate and reliable information on farming conditions, on agricultural practices, and on the incidence of diseases and pests. Such information is also useful in peace-time—for instance in the planning of research, but it was particularly necessary in war-time in planning the utilisation of scarce resources. The Statistical Department has been closely concerned with three major pieces of survey work of this kind : the Survey of Fertiliser Practice, the National Farm Survey and the Wireworm Survey. These projects are described in the detailed report.

The Survey of Fertiliser Practice revealed, amongst other things, the fact that farmers ploughing up old grassland had failed to

recognise the deficiencies of lime and phosphate so common in such land. The National Farm Survey deals with such aspects as tenure, condition of farm, incidence of insect pests, quality of farming and supplies of electricity and water. The object of the Wireworm Survey was to evolve methods suitable for assessing wireworm infestation of particular fields so that advice could be given to farmers on cropping and preventive measures.

The classical and other field experiments

Field experiments continue to occupy a prominent place in the Rothamsted programme, and in addition to the large number of experimental plots on the farms at Rothamsted and Woburn many field experiments have been carried out on private and institutional farms in various parts of the country.

For many years, there has been co-operation with Mr. A. W. Oldershaw at Saxmundham and Tunstall, and this has been continued. In spite of, or perhaps because of, the war the number of modern experiments as distinct from the classical experiments on the Rothamsted farm has increased greatly. There are long-term experiments, including rotation experiments, to study the effects of deep ploughing, various methods of returning straw to the land, the response of fertilisers in relation to season, and several other problems. There are also annual experiments in which the effects of treatments are measured in a single crop.

The classical experiments have been continued. The earlier work by the Botany Department on the reduction of the weed-seed population of arable land by fallowing led to the establishment of a five-year cycle on Broadbalk whereby one section is fallowed each year. Samples taken annually over a long period of years support the conclusion that the routine fallowing of one section per year has fully justified itself, as the weed-seed population has not only been kept in check but has also decreased during the 15 years that the system has been in force. This is particularly so in the case of poppy which has been decreasing steadily since periodic fallowing was instituted in 1925. Recently, however, trouble has arisen from the spread of species of wild oats, and special experiments are being carried out to find, if possible, some effective way of controlling this weed.

The botanical analyses of the herbage of Park Grass and High Field that were slowed up during the war years are now being dealt with, and the accumulation of analytical and observational data for many years is being examined and prepared for publication in order to bring the ecological history of the plots up to date.

Because of the urgent need for food production the non-experimental areas on the farm at Rothamsted were farmed as intensively as possible. Old grassland was broken up and the arable acreage increased from 137 in 1938-39 to 308 in 1944-45, whilst the value of the produce sold for these years rose from £2,922 to £7,401.

The timber in Knott Wood was not included when the farm was purchased in 1934, and, when it was felled, we were left with an area of about 74 acres of derelict land full of tree stumps. Part was replanted and part has still to be dealt with, but an area of about 24 acres was reclaimed in a variety of ways. In one section the land

was sown out to pasture without removing the stumps and without cultivation, in another cultivation was carried out, and in a third the tree stumps were also removed and the land has since been cropped.

The Crop Physiology Section has acted as a link between farm and laboratory, preparing the detailed plans of the field experiments and exercising general supervision from the laboratory side. This Section also carried out certain urgent investigations arising from the war. One of these was concerned with damage to crops that might be caused by war gases, and another with the storage of potatoes in clamps. These duties curtailed the work on the factors affecting leaf growth and leaf size on which the Crop Physiology Section is engaged.

Woburn Experimental Station

The work at Woburn (run by Rothamsted since 1926) has been continued under Dr. H. H. Mann. The light, somewhat sandy, soil is derived from the Lower Greensand and is in marked contrast to the fairly heavy soil from the Clay-with-Flints at Rothamsted. Woburn, therefore, provides a useful centre at which experiments carried out at Rothamsted can be repeated on a very different soil type.

The continuous wheat and barley experiments, commenced at Woburn in 1876, have been greatly modified, following fallows in 1927-28 and 1933-34 to get rid of weeds, and since 1940 the influence of previous manuring on the effectiveness of nitrogenous manures has been studied. Amongst the more recent work is a rotation experiment, similar to one at Rothamsted, with artificial manures only, which has been going on since 1930, and so far there is no sign of any deterioration in the crops. In 1938 an interesting long-term alternate-husbandry experiment was started to compare the fertility of soil, after three years under a grazed grass-and-clover ley, or under lucerne cropped annually for hay, with land which carries a well manured arable crop each year. Other experiments deal with cultivation problems, green manuring, the making of a market-garden soil, the manuring of sugar beet, take-all diseases of wheat and barley, and various other problems. Several lines of work are also being carried out in the pot-culture station including the studies on clover sickness commenced about 10 years ago : the conclusion has been reached that the disease is due neither to an eelworm nor to a fungus.

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DEPARTMENT OF PHYSICS

By B. A. Keen

Staff activities

Dr. Keen was President of the Royal Meteorological Society in 1938 and 1939, and Vice-President of the Institute of Physics. He was a member of the British Government Delegation to the Sofia University celebrations in May, 1939, and paid a second visit to Bulgaria in October-November, 1939, to report on problems of agricultural intensification and to select five agricultural scientists to come to England under British Council grants. In October, 1943, he was seconded as Scientific Adviser to the Middle East Supply Centre, Cairo, with the primary object of preparing a report and recommendations dealing with the agricultural development of some fourteen Middle East countries. The Report is now in the press, and will be published by the Stationery Office and the Oxford University Press. Dr. Keen also served on a Ministry of Supply committee on physical properties of explosives, and the soil stabilisation committees of the British Standards Institution and the Institute of Petroleum.

Dr. R. K. Schofield acted as Head of the Department in Dr. Keen's absence in the Middle East and replaced him on the above committees. He was appointed to the Ministry of Supply committee studying the mud-crossing performance of track-laying armoured fighting vehicles, and, at the request of the Meteorological Office, he also undertook with Dr. Penman special work on some problems of operational importance to the Royal Air Force. He was elected Chairman of the Physical Society Colour Group in 1945.

Dr. Russell was Chairman of the Hertfordshire County Garden Produce Committee.

Dr. Penman was seconded in September, 1941, for physical work in the Mine Design Department of the Admiralty. In April, 1944, he returned to Rothamsted at the request of the Air Ministry to join Dr. Schofield in special extensions of our work on transpiration and evaporation.

H. G. C. King, of the Assistant Staff, joined the Royal Air Force in May, 1941, and was commissioned as a pilot.

Besides the above activities, the departmental staff received a variety of requests for help and advice—usually involving rapid field or laboratory investigation—from organisations such as the Air Ministry and the Road Research Board.

For many years past, applications for admission to the Department as post-graduate voluntary workers have come from many different countries. The war drastically reduced the numbers, but the international aspect has been well maintained. Four voluntary workers obtained the Ph.D. degree of London University; H. C. Pereira (England): A. L. C. Davidson (Australia): R. V. Tamhane (India): and S. P. Saric (Jugoslavia). Others who spent a considerable period in the Department were: W. Balcerek (Poland); P. Boyanoff (Bulgaria), and A. Texeira (Portugal); the last two were in receipt of grants from the British Council.

Crops, soils and weather

The large variations in crop yield and quality from season to season are primarily caused by weather variations (1). In spite of this intimate association, only broad general relationships emerge, such as the low yield in a consistently cold growing season. The infinite variety in weather sequences, the local effects of topography and the physiological responses of the plants to environmental changes constitute too complex a system for ordinary analyses. Superimposed on this system there is the further complexity of plant pests and diseases, whose incidence also depends in intricate ways on weather factors. For these reasons, meteorologists and others have devoted attention to local climate variations which they endeavour to relate to minor topographical features on the one hand and to vegetation on the other. Botanists have carried the problem a stage further to the micro-climate, i.e., the meteorological elements within the few centimetres of air surrounding the leaves and stems of vegetation, in the belief that plant responses are due to micro- rather than macro-climate.

There is another line of attack, the physical, to which the two just mentioned are complementary for they must draw on the results of the physical researches in order to put them on a quantitative basis.

In its broadest terms the physical attack relies on studying energy balances between the meteorological, soil and vegetation factors. Experimentally, this involves examination of radiation, temperature, humidity, evaporation, transpiration, drainage, diffusion, winds and their inter-relations. For many years past the equipment of the meteorological station at Rothamsted, which is in charge of the Physics Department, has been steadily extended, especially by providing continuous recording instruments, and used for this purpose. It possesses a unique series of drain gauges, or lysimeters, and large soil cylinders in which crops can be grown and the water table maintained at required depths. This part of the equipment is essential for the exact study of crop-weather relationships.

Considerable attention has been given in fallow or bare-soil conditions to drainage and evaporation in relation to other meteorological and soil factors (2, 3, 4, 5, 6, 7). Thanks to the use of continuous recording instruments it is possible to pick out from the mass of records a series of "natural periods" for detailed study. A natural period is the period between one cessation of flow of the drain gauge and the next cessation: its duration may vary from a day or so to several months. The advantage of a natural period is that evaluation of the influence of the factors over the period can be more precise as overlapping effects are reduced to a minimum. The conclusions can then be applied to interpreting the results of arbitrary regular periods—month, week, etc.—that are standard for meteorological records and tables of normals.

The results show that the normal air data of a meteorological station are inadequate to predict the behaviour of the natural air-soil system under drying conditions. However, the results from the Rothamsted equipment, covering both air and soil factors, have led to some important generalisations. Seasonal variations in drainage

rate are almost wholly accounted for by the changes in viscosity arising from seasonal temperature changes. For a 20-in. depth of fallow uncultivated soil, the amount of water needed to cause waterlogging is about 0·3 in. in excess of the field capacity. During the rainless periods of a normal summer, the total water loss by evaporation (i.e., the deficit from field capacity) rarely exceeds 0·7 in. Thus there is a normal range of water content of only about 1·0 in.; in other words, the maximum air content in midsummer is about $\frac{1}{20}$, or 5 per cent. by volume. The figure for a similar soil also fallow, but cultivated is about 15 per cent. Seasonal changes in evaporation have been studied in both field and laboratory conditions and an approximate interpretation has been given in terms of water movements, as vapour and as liquid, in the soil, and of diffusive flow of vapour through a still boundary layer of air above the soil surface into the turbulent air above.

Recently (May, 1944) at the request of the Meteorological Office, arising from a problem in war operational research, measurements of evaporation were made from open water surfaces, and short grass with a water table near the surface, in addition to those from bare soil. The results have shown that the total annual water losses from the short grass is about three-quarters of that from the open water. From the viewpoint of crop-weather relationships it is important to extend this work to tall crops. This cannot be done in the present soil cylinders, as it is not possible to have round them the broad guard-ring of the same tall crop to prevent unnatural exposure of the plants growing in the cylinders. A separate and rather costly equipment will be needed for this purpose. Meanwhile some encouraging results have been obtained by indirect methods based on the suction techniques for measuring moisture deficits developed in the Department. Representative soil clods are taken from below the field crops and placed on filters containing water at a controlled suction of 50 cm. Their gain in weight is a measure of the water removed from them by the crop roots. The results show that barley up to the time of ripening has removed from the soil an amount of water approximately equal to the excess of the evaporation from short grass in the cylinders over the rainfall of the same period. The indication is that evaporation from a tall crop may be about the same as that from short grass.

Attention has also been given to the diffusion of gases and vapours through the soil (8, 9). The relation of diffusion rate to soil porosity is of importance both in meteorological and plant physiological work, and also has a technical interest in problems of soil fumigation. It was shown that diffusion through soil is a modified form of free diffusion in air, the modification depending only on the pore space when diffusion is steady. In the unsteady state solvent action by soil water, adsorption and chemical action may affect the results. Anomalous results of other workers for carbon dioxide were traced to the neglect of adsorption effects. The results also show that gaseous diffusion is adequate to account for normal soil aeration, and that the influence of meteorological changes is unimportant. It is also clear that diffusion of water vapour by distillation down a soil-temperature gradient makes a negligible contribution to the change in moisture content at any point.

In an analogous subject, the viscous diffusive flow of gases into plant tissues, a theoretical study was made of the porometer used by plant physiologists for the study of stomatal movements in leaves (10, 11).

Soil tillage

For a number of years past critical examinations of the effects of cultivation operations on the soil, soil moisture, plant growth and yield have formed an important section of the Department's work. The earlier results ran counter to certain of the traditions that have grown up around the subject, and, possibly for that reason, were received with scepticism. Later work, however, has confirmed the views set out in the previous investigations: crop yields are relatively insensitive to cultivation treatments; cultivations do not have the effects on soil-moisture control formerly attributed to them; weed control is most important in the early stages of crop growth. Since 1939 six papers have been published summarising various aspects of the results; two (12, 13) for general and scientific readers, two (14, 15) for agriculturists, and one (16) for horticulturists: the sixth paper (17) examines a large number of United States experiments on crop response to inter-row tillage, extending over many soils and seasons, and shows that they agree with our own results, in spite of the large differences in weather and soil and the use of different crops.

A three-year experiment in Surrey, on a loam soil overlaying sand and gravel, on the effect of inter-row tillage on potato yields was completed (18). Very low ridges were as effective as the standard high ridges in preventing green tubers and blight attack, and there was no difference in yields or in the relative proportions of ware, seeds and chats. In garden practice there seems no reason for ridging, but in commercial potato growing the present forms of implements for spraying and harvesting require high ridges for the reduction of haulm damage by wheels, and for ease in spinning out the tubers, especially in heavy soils. These experiments fell into line with the general conclusions already mentioned above; yields were insensitive to cultivation treatments but were appreciably reduced by even moderate weed competition in the early stages of crop growth.

The six-year cultivation experiment, begun in 1934, was completed. This compared, in a three-course rotation of wheat, mangolds and barley, the effects of the following cultivation treatments: plough and harrow, cultivator and harrow, rotary cultivation, each at shallow (3-4 in.) and deep (7-8 in.) levels. The results of the first three-year course were given in the Report for 1936, pp. 43-48, and the full results have now been published (19). They show no yield difference between deep and shallow working, with the possible exception that maintenance of mangold yields may require an occasional deep cultivation. The ploughing treatment was better than the other two, for the probable reason that it showed the most efficient weed control.

Earlier work on inter-tillage of sugar beet suggested the importance of weed control in the early stages of crop growth, so experiments in 1939, 1940 and 1941 were directed to this point, both on

the sandy Woburn soil and the heavy stony Rothamsted soil. The results (20) show that on the Woburn soil the effect of weeding depends on the level of soil fertility. The yield of the manured plots was not improved by weeding, and a considerable infestation caused no decrease in crop, but the yield of the unmanured plots was increased by weeding provided it was done in the early stages of crop growth. In the heavier Rothamsted soil the effect of cultivation did not alter with the level of fertility. There was some indication that whereas hoeings after singling, above a modest minimum, produce either no effect or a reduction in yield, a cultivation before singling time could produce an increase.

A new cultivation-rotation experiment was begun in the autumn of 1943. The object of this experiment is to compare the effects of deep (about 12-in.) with shallow (about 6-in.) ploughing and the effectiveness of potash and phosphate applied in the spring in the seedbed with that of applications in the autumn just before ploughing. A six-course rotation—wheat, potatoes, oats, sugar beet, barley, seeds—is used and the deep-ploughing treatment is given in preparation for the wheat, potatoes and sugar beet, i.e., three times in six years, and the comparison of the method of incorporating the potash and phosphate is tested on the potatoes and sugar beet. The results of only two harvest years are so far available, and are in consequence provisional : but in the dry summer of 1944 the sugar beet seemed to do best on the deep-ploughed plots in which potash or phosphate were ploughed in, and in the moist summer of 1945 the potatoes seemed to respond well to the deep-ploughing.

Ever since the beginning of our cultivation studies we have been hampered by the absence of facilities for carrying out even simple experiments at other places besides Rothamsted and Woburn : indeed the only satisfactory outside experiment—the three-year one on potatoes in Surrey (18)—arose from the chance that a resident there was able to carry out work for a Ph.D. thesis on cultivations, under the writer's direction. As long as this unsatisfactory situation continued we were in no position to deal with the frequent statements of agriculturists and others that yields on their soils, unlike those at Rothamsted and Woburn, were responsive to cultivation. At the end of 1942 a full statement of the results to date was made to the Agricultural Research Council, and the need for further work was urged. Large numbers of heavy implements capable of deep work were in use, especially under the charge of the War Agricultural Executive Committees, and there was little or no evidence whether the extra call on limited fuel stocks needed by a deeper working of the soil would be justified by an increased crop yield. Eventually, the necessary implements were made available and a programme of work was authorised, the results of which are supplied to a joint sub-committee of the Agricultural Research Council and the Agricultural Improvement Council. The experiments are carried out in association with the County War Agricultural Executive Committees, usually through their Technical Officers, and the arrangement works very well. The work began in the autumn of 1944, and was confined to potatoes—a crop for which deep cultivation is considered very important—with the following

four cultivation treatments : 7-8 in. ploughing ; the same, with subsoiling to a total depth of about 12 in. ; 13-15 in. ploughing ; the same, with subsoiling to a total depth of about 18-20 in. Fourteen centres were selected covering the following range of soil types : clay-with-flints, chalky boulder clay, boulder clay, London clay, clay fen, Lower Lias clay, sand over Lower Lias clay, old reclaimed gravel and sand heath, Old Red Sandstone alluvium. The results for the 1944-45 season were striking. The wide range of cultivation treatments produced no effect on yield, with the one exception of a very wet field where deep ploughing was beneficial. Nor were there any notable differences in the response to fertilisers with the different depths of cultivation. There is the possibility that in seasons like 1944-45, which was favourable for plant growth, cultivation differences, like manurial ones, will be smoothed out. The experiments will, therefore, be continued. A further set of deep-ploughing experiments on other sites and covering further soil types was begun in the autumn of 1945. Assistance has also been provided for a preliminary study of the root ranges of growing plants that may help to explain the effects of weeds already discussed above.

A significant extension of the field work of the Department was an investigation of the relative efficiency and behaviour under normal farm usage of various types of pneumatic tyres and standard steel wheels, and the effects, in differing soil conditions, of various modifications such as loading, inflation pressure. The work was done at Rothamsted and Woburn at the joint request of the British Rubber Producers' Research Association and the British Rubber Publicity Association. At an early stage of the work it became necessary to devise a simple and accurate method of measuring the tractor performance over quite short runs, so that the field tests could be kept within a reasonable compass of time and area (21). The elaborate equipment used for testing tractor performance was unavailable, and in any case was inapplicable in the present work. By fitting an auxiliary small fuel tank, in which the fuel consumed could be accurately measured, a number of separate experiments can be made and statistically analysed, the length of run in each experiment being only between 50 and 175 yards. The recorded measurements of fuel consumed are corrected for certain variable factors, such as drawbar pull, gear ratio and speed of ploughing, and the corrected results give a measure of the tractor efficiency and, therefore, of the tyre performance in the particular experiment. The method has since been adopted by other investigators. Its use in the present investigation (22) brought out the following points.

Tyre performance depends more on adequate ballast than inflation pressure. Low pressures were useful only in wet conditions and when extra ballast is unavailable, and high pressures promote excessive slip. Extra ballast, especially over the landside wheel, whose load is reduced by the tilt of the tractor, improves the performance. Except for loose soil and wet turf, a large outside tyre diameter is more important than a wide section. Wheel slip, as usually measured, gives values higher than the real slip. The tyre casing and tread are compressed horizontally by the pressure that

the treads must exert on the ground to move the tractor forward. The movement of the tyre on the ground is concertina-like, and this reduces the effective circumference of the tyre so that it appears to be slipping, although there may be little or no relative movement between tyre and soil. Measurements of plaster casts of the soil impressions left by a tractor running light and heavily loaded showed that practically all of a measured " slip " of 8 per cent. was accounted for by the apparent slip just described.

Soil structure and moisture relationships

Previous reports and published papers have developed the exact physical picture of the way water is held and moves in a soil. The theoretical and practical work of Haines* disclosed the hysteresis effect, i.e., there is no unique or single value for the soil-moisture content at a given equilibrium condition, and the actual value depends on how that equilibrium is approached. Haines's work was based on considerations of the geometry of the soil pore space and the curvature of the water films, and was therefore confined to coarse-grained material, such as sand and very light soils. Later, Schofield† gave a generalised treatment of hysteresis, based on energy considerations, and therefore applicable to all soils, and he also provided, over a wide range of suction values, experimental proof of its reality. Subsequent work in the Department has examined and extended the experimental techniques available for measuring the suction values corresponding to different moisture contents (23). It has been shown that an apparatus of the " filter " type, i.e., a porous pot or plate containing water and connected to a manometer, gives reproducible values for suctions up to about 400 cm. instead of up to one atmosphere, which is the theoretical maximum for these instruments. Measurements of suction by the freezing-point-depression method, on the other hand, are not reliable at suctions below about 4 atmospheres. The reason is that the freezing-point depression is due not only to suction but to the soluble salts in the soil moisture. The latter effect makes an appreciable contribution to the total depression at the soil-moisture contents corresponding to suction values below 4 atmospheres, and it is difficult to assess it accurately and so to arrive at the effect due to suction only. For use over the important suction range 400 cm. to 4 atmospheres, thin absorbent plates of Portland stone have been tried and found suitable. They are placed in contact with the soil and their equilibrium moisture content determined. They were calibrated up to one atmosphere by a suction technique, and from one to 4 atmospheres by vapour-pressure-depression measurements.

Problems of moisture distribution and movement concern not only agriculturists. They are of importance to water-works and irrigation engineers, to civil engineers and builders concerned with the pressure and stability of foundations, roads, etc. From an inspection of the considerable technological literature that has grown up around the engineering aspects of these subjects, under the name of " soil mechanics," and from the nature of the requests for help received by the Department from those concerned, it is

* J. Agric. Sci. (1930), **20**, 97-118.
† Trans. Third Int. Congress Soil Sci. (1935), **2**, 37-48.

clear that the part played by moisture distribution and movement in their problems is not yet fully appreciated. A paper was, therefore, prepared, addressed especially to engineers, on the role of soil moisture in soil mechanics (24), setting out the mechanism of water distribution as it is now understood.

Soil structure, or the geometrical specification of particle arrangement, and its degree of permanence or impermanence are of basic importance in the study of soil tilth and the modifications produced by weather and cultivation operations. The experimental methods can be classed in two groups : (*a*) those which measure the size distribution of the clods and crumbs in the soil, and their degree of resistance to disintegration forces, (*b*) those which deal with the clod and crumb geometry—the volume of pore space, and of air and water in the pores.

Some methods in the first group have been examined (25). Simple passage through a nest of sieves gives information on size distribution of clods in field conditions, and on the effect of cultivation implements. For the smaller sizes of aggregates—the soil crumbs that characterise tilth—some measure of their stability is required. It is usually considered that tilth is related to the more resistant soil crumbs and, in default of any absolute definition of a resistant aggregate, the criterion taken is the ability to withstand slaking in water. Some degree of empiricism is inevitable, for the aggregates are not absolutely water-stable, and the results obtained will therefore depend on the way the slaking is carried out. The drastic method of slaking by sudden immersion in water was compared with the gentle ones of very slow wetting and wetting under a vacuum to avoid the disruptive effect of air evolution : the choosing of a particular method depends on the kind of information required, e.g., if stability under flood-irrigation conditions is the problem, the immersion technique would be the most suitable.

In the second group of methods dealing with the volume measurements of pore space, air and water in the clod or aggregate, a variety of techniques is available for use with permeable stoneless soils, but for impermeable soils and, in particular, the stony " clay-with-flints " soil at Rothamsted no accurate method of a reasonable simplicity has hitherto been in use. Existing methods, based on forming an impervious coating around the clod of soil, either fail or have a low accuracy for damp clods. A method has now been developed (26) using a liquid that is immiscible with water and that is also non-polar, so that no appreciable swelling of the clod occurs. Paraffin was found to be suitable, after purification by shaking with finely divided damp soil and then with dry silica gel. The moist clod is weighed in air : then it is immersed under vacuum in paraffin which replaces the air in the clod and it is weighed in the paraffin : finally it is weighed in air when full of paraffin. A simple calculation from these three weighings gives the total clod volume, the volume of air and the volume of the soil particles plus the water, from which the water volume can be obtained by a subsequent determination of the volume of the soil particles. The accuracy of the field-volume and air-space measurements is at least 0·1 per cent. By bringing the clods to equilibrium with water at two definite suction values—the well-drained or field-capacity

condition, and the wilting point— measurements of the water available to plants can be made. Tests of the soil from the farmyard-manure and unmanured plots of the classical field experiments at Rothamsted show that the long-continued applications of farmyard manure have increased the available water in the top 9 in. by about 35 per cent., although in the air-dry condition the air space in the clods of the manured soil is less than 2 per cent. greater than that of the unmanured soil. An interesting difference between the top soil and subsoil of the manured area is that the natural shrinkage on drying is much greater in the subsoil. The effect is not yet fully understood, as it cannot be entirely accounted for by the difference of organic matter content.

Properties of soil particles. Of the various fractions of soil, clay is the most interesting and important. It consists of all particles whose diameter, as calculated from Stoke's Law, does not exceed 2μ or 0·002 mm. It has long been apparent that sub-division of the clay fraction into groups of smaller diameter limits is desirable, because the properties are not distributed evenly over the diameter range : in general, the finer the particle the more marked are the properties. In the usual sedimentation method of mechanical analysis, impossibly long settling times would be needed for the sub-divisions if sampling were carried out at the normal depths. A study (27) has been made of the use of much shallower sampling depths with their correspondingly shorter sampling times. It was shown that the standard apparatus could be employed at a sampling depth of only 2 cm. instead of the usual 10 cm., without error, and that with special fine-point pipettes, e.g. a hypodermic needle, samplings as shallow as 2·5 mm. can be made. These factors, coupled with the use of a constant temperature enclosure to prevent convection currents, have made it possible to obtain sub-fractions down to a diameter of about $0{\cdot}1\mu$, which corresponds to a settling time of 11·5 days for 1 cm. In fact, the limitations to further sub-division lie more in difficulties with the dispersion than in the sampling technique itself. Using caustic soda as dispersion agent, the first effects are the desirable and necessary ones : adequate dispersion and stabilisation of the clay particles. But with increasing soda concentration the particles no longer settle independently, and the suspension behaves like a weak thixotropic gel, and, at a later stage, loses its homogeneity and practically flocculates.

In addition to the scientific aspects of subdividing the clay fraction, it is likely—to judge by some preliminary results—that there will also be agricultural aspects of significance. Size distributions in the clay fractions have been determined for clay soils from different formations. It appears, for example, that the Weald clay—which, although difficult to work cracks less than normal clays, such as the Gault—contains less clay in the finest fraction. Again, fruit soils on the Triassic and Old Red Sandstone formations, often have a lower proportion of the finest clay particles than pasture soils on this formation, although the total clay content is much the same.

Examination of clay particles by physico-chemical methods has shown by means of chloride-retention studies that positive charges

as well as negative ones appear to be associated with the clay particle (28). The observation is of importance, because if, as seems possible, positive charges are present up to pH 7·5, they may affect the power of the clay to retain nutrient ions such as phosphate. Further, there is some suggestion that thixotropic effects are promoted by the positive charges, in which case they would have an important role in determining soil structure. The nature of these basis groups has yet to be worked out, in particular, whether they are an integral portion of the clay proper—in which case they should be related to the structure as revealed by X-ray analysis—or whether they belong to the small amount of amorphous material associated with the clay.

Organic matter. Physico-chemical studies of soil organic matter show that, like clay, it is a highly complex material. Considerable progress has recently been made. When measurements were first made of base uptake by soil as a function of pH, it was observed that more $Ca(OH)_2$ was taken up than $Ba(OH)_2$, and more $Ba(OH)_2$ than NaOH or KOH. This non-equivalence was used to combat the view that base uptake by soil was analogous to the neutralisation of an acid. It has now been shown (29) that solid substances, such as wood, peat and their constituents, exert buffer action simply by virtue of the dissociation of hydrion from specific chemical groups. It has also been shown that some relatively simple organic acids, such as acetylacetone, exhibit non-equivalence of alkali uptake or, more exactly, exhibit different dissociation constants according to the cation of the alkali used to neutralise them. The cause has been traced to the formation, by co-ordination, of a chelate compound with the ion. These compounds can only form when there is a particular molecular configuration, and it is quite reasonable to suppose that such configurations exist in soil organic matter. Thus a phenomenon that appeared to challenge the rational interpretation of buffer action in soil organic matter can now be used as a tool to assist in unravelling the details of the structure of these and similar complex materials.

Other work

Earlier studies on the measurement of soil colour directed attention to deficiencies in the standard colorimetric instruments, especially in the transformation of the experimental values to the international scale (C.I.E.). Dr. Schofield (30) has devised an addition to the Lovibond Tintometer—an instrument in wide use for measuring and recording colour—which overcomes this difficulty and, in addition, greatly simplifies the process of transformation to the C.I.E. scale. The device is now a standard feature of the instrument.

PUBLICATIONS

1. Keen, B. A. 1940. *Weather and crops.* Q. J. Roy. Met. Soc., **66**, 155-166.

Presidential address to the Royal Meteorological Society, 1940. A review of progress made in the study of the effects of seasonal weather variations on plant growth since 1900. The results of the closer mathematical examination of crop-weather relationships, originated and developed by R. A. Fisher, at Rothamsted, are briefly outlined. The possibilities and limitations of prediction formulae for yields are discussed.

2. PENMAN, H. L. 1940. *Meteorological and soil factors affecting evaporation from fallow soil.* Q. J. Roy. Met. Soc., **66**, 401-410.

Using the conception of natural periods, for which the difference between rainfall and drainage can be equated to the evaporation, the mean daily rates of evaporation from a block of fallow soil at Rothamsted are examined for 94 periods varying in length from 13 to 45 days. In seeking correlations with single daily meteorological observations two types of treatment are employed. 1. The year is considered in three seasons of four months each—summer, winter and two equinoctial pairs of months—and it is shown that an almost complete description of evaporation can be obtained in terms of rainfall only, the nature of the correlation varying from season to season. 2. A general treatment is attempted in physical terms, considering evaporation as due to diffusion across a non-turbulent boundary layer whose thickness is determined by wind velocity, the soil surface being assumed to be continuously at 100 per cent. relative humidity (R.H.). The general agreement between observed and predicted values is very good in winter. The summer data are shown to lie between the theoretical limits imposed by the assumptions of (i) continuous 100 per cent. R.H. at the surface, and (ii) a steady retreat of the 100 per cent R.H. layer into the soil, i.e., no upward movement of *liquid* during the evaporation process.. The considerable scatter in the data is attributed partly to the inadequacy of single daily meteorological observations but chiefly to the lack of knowledge of the conditions existing at the soil surface.

3. SAHNI, P. N. 1941. *The relation of drainage to rainfall and other meteorological factors.* J. Agric. Sci., **31**, 110-115.

Natural drainage periods, i.e., periods between consecutive cessations of flow of the Rothamsted 20 in. drain gauge, were selected for the months of June, July and August. All periods of from 2 to 13 days were taken.

A curvilinear relationship between the difference of rainfall and drainage (deficit) and rainfall was established.

Residuals from this curve showed no appreciable correlation with the mean air temperature, but there was some slight evidence that the deficit was increased by a decrease in relative humidity or an increase in wind velocity.

The residuals showed little correlation with drainage during the previous three weeks.

4. PENMAN, H. L. and SCHOFIELD, R. K. 1941. *Drainage and evaporation from fallow soil, at Rothamsted.* J. Agric. Sci., **31**, 74-109.

There is a seasonal change in the drainage response after rain which can be almost wholly ascribed to viscosity changes arising from seasonal changes of soil temperature.

Natural periods can be chosen over which the difference between rainfall and drainage can be equated to the evaporation. Good approximations are : periods of a year, six months, or long series mean of individual calendar months. A single calendar month will rarely approximate to a natural period.

Summer evaporation is two to three times as great as winter evaporation ; the former is dependent and the latter independent of rainfall. Consideration of the physical basis of evaporation in relation to the vapour pressure gradient in the air immediately above the soil surface brings out the following points :

(*a*) In winter the soil does not dry at the surface. Winter evaporation is, therefore, much the same as would be obtained from a water surface and extra rainfall does not affect it.

(*b*) In summer the surface remains moist only for a short time after rain has fallen ; the air gradient is then much steeper than in winter. For the rest of the time the surface is drier and there is also a vapour pressure gradient in the soil. Hence (i) there is more rapid evaporation while the surface is wet ; (ii) the total amount of evaporation is dependent upon both total rainfall and on its distribution in time ; (iii) the later stages of evaporation are more dependent upon soil conditions than on air conditions, and (iv) the total evaporation is much less than from open water.

(*c*) An adequate description of evaporation in all seasons may be obtained from knowledge of the difference in the partial pressures of the water vapour of the air in and above the soil surface. In the general evaporation equation this term is the most important, and the impossibility of representing changes in it in terms of changes of rainfall and mean air temperature alone accounts for the apparent anomalies in the results of previous statistical treatments.

5. PENMAN, H. L. 1941. *Laboratory experiments on evaporation from fallow soil.* J. Agric. Sci., **31**, 454-465.

Laboratory experiments on evaporation from freely drained soils are described. Under " isothermal " conditions (i.e., the soil is kept at air temperature, apart from surface cooling, produced by evaporation) characteristic *winter* field behaviour is obtained, even when the air drying power is greater than its normal English midsummer value. Characteristic *summer* field behaviour is obtained when the rapid drying of a thin surface layer is achieved either by using an extremely high air temperature under " isothermal " conditions, or by raising the surface temperature by means of radiation—the normal method in nature. The effect of a high salt concentration in the soil water is shown to lead to greater evaporation losses and to a tendency for the salt to concentrate in the more salty patches.

It is suggested that mulching will only be beneficial during the isothermal part of the year, i.e., when soil surface and air temperature are approximately equal, and that it will have little effect on water conservation where the soil will be self-mulched by the action of summer sunshine. The cause of this self-mulching action is briefly considered in the light of our limited knowledge of soil water dynamics ; it appears to depend on the existence of a dual mechanism of water movement in soils—as liquid and as vapour—the rates of movement being very different functions of moisture content and moisture gradient.

6. PENMAN, H. L. 1943. *Daily and seasonal changes in the surface temperature of fallow soil, at Rothamsted.* Q. J. Roy. Met. Soc., **69**, 1-16.

A method of obtaining continuous records of soil surface temperature is described and 15 months' records are discussed.

The relations between surface and sub-surface temperatures are briefly considered, and then, in more detail, the inter-dependence of soil surface and air temperatures is examined. At all seasons the soil temperature is in phase with solar radiation whereas the maximum air temperature is delayed ; for air maxima below 52°F. the daily range of soil surface temperature is approximately the same as that of the air temperature. Above this threshold the soil surface maximum increases twice as rapidly as the air maximum. Using this value of the air maximum, 52°F., to divide the year into two seasons, it is found that the winter and summer periods so separated are the same as those previously obtained from the criterion : seasonal evaporation is equal to or less than that from an open water surface. Interest is primarily centred on the summer season, in which the soil surface temperature exceeds that of the air for a considerable part of the day, and for a rainless summer period of t days an anticipated relation of the form $\sum E = at^{\frac{1}{n}}$ where $n = 3$, a is a constant and $\sum E$ = the total evaporation, is confirmed from the Rothamsted records.

The effect of the diurnal oscillation of surface temperature on germinating seed is briefly discussed.

7. SCHOFIELD, R. K. 1940. *Note on the freezing of soil.* Q. J. Roy. Met. Soc., **66**, 167-170.

A short paper dealing with the cold weather of early 1940, and explaining the soil temperature observations in terms of the water movement within soil interstices of differing sizes that occurs when ice forms, and the latent heat of thawing.

8. PENMAN, H. L. 1940. *Gas and vapour movements in the soil.* I. *The diffusion of vapours through porous solids.* J. Agric. Sci., **30**, 437-462.

The dependence of the coefficient of diffusion, D, upon the porosity, S, of a granular solid is investigated experimentally. For steady state conditions, using carbon disulphide and acetone vapours, it is shown that a curve connecting D/D_0 and S can be drawn which is independent of the nature of the solid, its moisture content and, within limits, its texture. For a limited range of values of S ($0{\cdot}0 < S < 0{\cdot}7$) a good approximation is $D/D_0 = 0{\cdot}66S$ and over this range the diffusion coefficients are larger than those found by Buckingham for carbon dioxide.

Investigation of the non-steady state shows that in soils the attainment of pressure equilibrium is retarded by adsorption, and it is suggested that Buckingham's low values for steady-state conditions can be attributed to premature observations of the diffusion rates ; the steady state had probably not been attained when his measurements were made.

9. PENMAN, H. L. 1940. *Gas and vapour movements in the soil.* II. *The diffusion of carbon dioxide through porous solids.* J. Agric. Sci., **30**, 570-581.

Apparatus for measuring the rate of diffusion of carbon dioxide through granular solids is described and the results obtained with it are shown to conform to the curve connecting D/D_0 and S previously obtained for carbon disulphide and acetone. The equation $D/D_0 = 0{\cdot}66S$, which it is suggested should replace Buckingham's equation $D/D = S$-, is applied to a discussion of soil aeration, and it is shown that at all porosities the rate of diffusion of carbon dioxide from the soil is sufficient to account for normal respiration without invoking the assistance of meteorological changes. A further application of the equation to water vapour movement in soils is briefly discussed.

10. PENMAN, H. L. 1941. *Theory of viscous flow porometers.* Appendix to paper by O. V. S. Heath. Ann. Bot., **5** (New Series), 455-500.

11. PENMAN, H. L. 1942. *Theory of porometers used in the study of stomatal movements in leaves.* Proc. Roy. Soc., B., **130**, 416-434.

The mathematical theory of porometers, as used by Gregory and his collaborators for the study of stomatal movements in leaves, is given for viscous and diffusive flow of gases. It is shown that under certain conditions the theory applies to both kinds of gas movements ; a correction is included for those cases in which the basic assumptions for diffusion are not realised. From determinations of the total leaf resistance to gaseous flow the conductance of the stomata can be found if the mesophyll resistance is known. The importance of this quantity is discussed and demonstrated, methods of measuring it are suggested, and possible checks upon the reliability of the results are described.

As an illustration, the theory is applied to some hitherto unpublished data on two pelargonium leaves ; the treatment gives results that are internally consistent, and deduced rates of assimilation are found to be of the same order of magnitude as those observed in practice.

12. KEEN, B. A. 1942. *Soil physics : theory and practice.* J. Roy. Soc. Arts, **90**, 545-579.

The Cantor Lectures to the Royal Society of Arts, 1942, dealing with (*a*) soil physics ; its scope in agriculture ; (*b*) soil cultivation—art or science ? (*c*) cultivation and crop yields.

13. KEEN, B. A. *Progress in the fundamental study of soil, soil moisture, and soil tillage,* 1912-1945. (In the press.)

A paper contributed to the Prasolov Jubilee Scientific Session of the Dokuchayev Soil Institute, Moscow.

14. KEEN, B. A. 1938. *Are cultivations overdone ?* J. Min. Agric., **45**, 645-652.

A summary of the Rothamsted work on cultivation up to 1938 on subsoiling, extra ploughings, seed-bed consolidation, intensive inter-row cultivation of root crops, rolling and harrowing, depth of tillage and rotary cultivation.

15. RUSSELL, E. W. 1945. *What are the minimum cultivations necessary for high farming ?* Proc. Inst. Brit. Agric., Eng., **3**, 99-111.

A summary of the cultivation work up to 1944 showing that agricultural crops are far more sensitive to weeds than to tilth, and hence that early hoeing (and possibly deep ploughing also), by giving good control of weeds, is very important. It is further suggested that the crop itself can become an excellent cultivator of the soil, for a crop sown in good time and given really adequate dressings of manure and fertiliser, will prevent weeds developing and will forestall the intensive cultivation programme that patchy and half-starved crops need.

16. KEEN, B. A. 1942. *Hoeing.* J. Roy. Hort. Soc., **67**, 323-328.

A review of the results on hoeing of farm crops with reference to their application to horticultural practices and ideas.

17. Pereira, H. C. 1941. *Crop response to inter-row tillage.* Emp. J. Exp. Agric., **9**, 29-42.

Inter-row tillage of crops has been tested in the U.S.A. by many simple field trials with maize, and by several well-replicated modern trials with market-garden vegetables. The results have shown the maintenance of a soil mulch between plant-rows to be of little importance in the absence of weeds. The experiments emphasised the importance of weed-destruction. British evidence on inter-row tillage is scarce, but the data available confirm the findings of the American workers.

18. Pereira, H. C. 1941. *Studies in soil cultivation.* IX. *The effect of inter-row tillage on the yield of potatoes.* J. Agric. Sci., **31**, 212-231.

The experiments conducted in the years 1937, 1938 and 1939, indicate that for a well-drained sandy loam, under a considerable range of moisture-supply conditions, main-crop potatoes do not respond in the absence of weeds to ridging-up, or to deep or frequent inter-row grubbings, by any increase in yield or in the percentage of ware. The crop showed successful powers of adaptation to a range of contrasting inter-row tillage treatments.

The potato crop showed considerable sensitivity to weed competition in the early stages of growth. This indicates that it is of great importance to maintain the crop in a weed-free condition during this early period.

Inter-row tillage operations on this type of soil should, therefore, be designed to destroy weeds and to provide moderate cover for the tubers. Intensification of such tillage beyond these limits is not of direct benefit to the plants.

No moisture-conservation effect of any importance was produced by a 3-in. soil mulch during dry weather, even when the water-table lay within 4 ft. from the surface.

19. Russell, E. W. and Keen, B. A. 1941. *Studies in soil cultivation.* X. *The results of a six-year cultivation experiment.* J. Agric. Sci., **31**, 326-347.

The results of a six-year cultivation rotation experiment are given. The rotation used was wheat-mangolds-barley and the seed-beds for these were prepared either by ploughing, using a rotary cultivator or a tractor-drawn grubber.

The yields of these crops were barely influenced by the depth of ploughing, a 4 in. depth giving throughout the six years just about the same yield as an 8 in. depth. The mangold crop was possibly a little larger on the deeper ploughed plots.

The mean yields of the seed-beds prepared with the tractor-drawn grubber or cultivator followed by harrows, etc., were lower than the ploughed seed-beds for all the crops, and this was particularly so on those seed-beds prepared by only one grubbing down to 4 in. depth.

The mean yields on the seed-beds prepared by the rototiller were lower than on the ploughed seed-beds for wheat and mangolds. If the seed-bed was prepared by rototillage to a depth of 8 in. by going over the land twice, the yield of barley was the same as on the ploughed seed-beds, but was definitely less on the seed-bed rototilled only once to 4 in.

Seed-beds prepared by the rototiller or grubber have only a small residual effect on the crop yields in the following year.

It is concluded that the primary function of ploughing is weed control, and that it is only advisable to omit ploughing either if the land is already fairly clean or if the crop will be hoed very early on in its development.

For wheat and mangolds differences in weed infestation of the seed-bed were probably of greater importance than differences in tilth in so far as the crop yield was concerned. The reverse may have been true for barley.

20. Russell, E. W., Keen, B. A. and Mann, H. H. 1942. *Studies in soil cultivation.* XI. *The effect of inter-tillage on the sugar beet crop.* J. Agric. Sci., **32**, 330-337.

Experiments on the effect of inter-row cultivation of sugar beet, carried out in the three years 1939-41 on a sandy loam, led to the following results:

(1) If the soil nutrients are in short supply hoeing or hand-weeding increases the yield of the beet, provided these operations are carried out before or shortly after singling.

(2) Hoeing is more effective than hand-weeding, but it cannot yet be said with certainty whether this is due entirely to more efficient weed destruction, or whether there is some additional effect, such as mulching.

(3) If adequate quantities of soil nutrients are present, inter-row cultivation has little effect on yield, and the crop can tolerate a considerable weed infestation without any effect on yield.

The results for sugar beet on the heavy clay-with-flints soil at Rothamsted show :

(1) Additional hoeings after singling, above a modest minimum, have either no effect on yield or else depress it.

(2) On the one occasion when pre-singling cultivations were given, the yield was increased.

(3) In contrast with the Woburn results the effect of cultivation does not vary with the level of manuring.

21. Russell, E. W. and Hine, H. J. 1941. *On measuring the efficiency of a tractor by its fuel consumption.* Emp. J. Exp. Agric., **9**, 98-110.

An investigation has been made on how accurately the fuel consumed by a tractor running over distances of 2 to 8 chains (44 to 176 yards) can be measured. It has been shown how the crude measurements can be corrected for certain variable factors, and that when this has been done it is comparatively easy to measure the fuel consumed to about 3-5 per cent. per run.

Examples are given of the kind of results that can be obtained and the precautions that must be taken to ensure that the results are correctly interpreted.

22. Russell, E. W., Hine, H. J. and Keen, B. A. 1942. *The efficiency of pneumatic tyred tractors under farm conditions.* J. Agric. Sci., **32**, 1-42.

(1) Increasing the ballast on pneumatic tyres, up to a certain weight, improves the tractor performance as judged by its speed, fuel consumption and wheel slip. Further increases beyond this point continued to decrease the wheel slip without having any marked effect on its speed or fuel consumption. No certain evidence was obtained that too heavy a ballast decreased the tractor's efficiency.

(2) The tyre load affects the maximum pull the tractor can exert while working reasonably efficiently, but this pull does not depend markedly on the speed of work. Wheel weights of about 12-13 cwt. seem to be the minimum required for optimum performance of the 36 or 28 in. tyres at pulls of 1,800 lb. under fairly good ground conditions, and possibly a greater weight may be required by the 24 in. tyre.

(3) If the tractor is ploughing it is usually running tilted, and this tilt transfers sufficient weight on to the furrow wheel for it to work efficiently under most conditions. Additional ballast is, however, often necessary for the lighter land-side wheel.

(4) Tyre performance is much less dependent on inflation pressure than on ballast. Pressures below 10 lb./sq. in. were only of use in wet conditions when small amounts of additional ballast were not available. Pressures above 12 lb./sq. in. may allow excessive slip to take place and probably only need be used on the furrow wheel of a well-loaded tractor ploughing.

(5) The effect of pneumatic tyres and standard steel wheels on tractor and wheel performance depends on both tyre diameter and tyre section, and varies also with the type of soil and its condition. In general, a large outside diameter for a tyre appears to be more important than a wide section for all except loose soil conditions and possibly wet slippery turf.

(6) The fuel consumption per acre was higher for the tractor working in bottom than in second gear, and this effect can account for about half the difference in fuel consumption between the 36 and 24 in. tyres. This is not an effect of speed of work, for the fuel consumption was independent of the speed of work within this range if the speed was varied by altering the governor setting on the tractor engine but keeping the tractor in second gear.

(7) The tractor fitted with pneumatic tyres was able to plough or cultivate as well as when fitted with steel wheels under all soil conditions with only a few exceptions, none of which could be examined in detail owing to the transitory existence of the unfavourable soil conditions.

23. Davidson, A. L. C. and Schofield, R. K. 1942. *Measurement of the suction of soil water by Portland stone absorbers calibrated by a new method for determining vapour pressures near to saturation.* J. Agric. Sci., **32**, 413-427.

(1) A filter apparatus cannot be relied upon to give a correct reading of the suction of soil water when this exceeds about 400 cm. of water.

(2) Owing to the contribution of dissolved matter to the freezing-point depression the suction in a soil of normal low salt content can only be obtained from the freezing-point depression with reasonable accuracy when it exceeds about 4,000 cm. of water (freezing-point depression greater than 0·3°C.).

(3) Suctions in the range 400 to 4,000 cm. have been measured with the aid of calibrated absorbers consisting of thin plates of Portland stone.

(4) The plates were calibrated up to 1,000 cm. by the application of suction through a filter, and above 1,000 cm. by measuring the vapour-pressure depression by a new technique.

(5) When applied direct to soil, the new vapour-pressure technique is more reliable than the freezing-point method, and can be applied to materials which do not exhibit a well-defined freezing-point.

(6) A suitable soil was washed free from salts and brought to 1,000 cm. suction on a filter. Measurements of the vapour-pressure depression and the freezing-point depression checked well with the thermodynamic formulae.

24. Schofield, R. K. 1943. *The role of moisture in soil mechanics.* Chem. Ind., **62**, 339-341.

This paper is addressed to engineers concerned with soil problems. It outlines the present-day conceptions on water distribution and movement, and its relation to soil properties such as pore space, base-exchange, and the bearing of these on practical problems.

25. Russell, E. W. and Tamhane, R. V. 1940. *The determination of the size distribution of soil clods and crumbs.* J. Agric. Sci., **30**, 210-234.

(1) It is possible to determine the size distribution of clods in the field by simple sieving of the soil without any pre-treatment provided the soil is not too wet. There is a personal factor involved in the sieving, but with care and training this will not affect comparisons of results obtained by that person.

(2) There appears to be no best method for determining the size distribution of the soil crumbs, i.e., of the water-stable aggregates in the soil. The method and the technique must be chosen so as to give the maximum amount of useful information. If an appreciable proportion of the crumbs are larger than $\frac{1}{4}$ mm., a water-sieving method is practically essential.

(3) The method of wetting to be used can only be chosen from a consideration of what information is wanted. If possible it would be desirable for general purposes to use both a very slow or a vacuum wetting technique and a very rapid wetting technique such as wetting the soil by immersion in water.

(4) The decision whether air-dry or field-moist soil should be used depends entirely on the information needed. For general purposes the use of air-dry soil is recommended.

(5) It has been found possible to separate the crumb fractions of Rothamsted soil into crumbs and sand particles by carefully dispersing them in a bromoform solution of the correct density. The crumbs float and the sand particles sink.

(6) A rapid method of overcoming this difficulty of distinguishing between crumbs and sand particles in a crumb fraction is to determine the proportion of the total base-exchange capacity of the soil that is in each crumb fraction. Schofield's potassium carbonate method for doing this is described.

26. Russell, E. W. and Balcerek, W. 1944. *The determination of the volume and air space of soil clods.* J. Agric. Sci., **34**, 123-132.

A method is described for determining the field volume and the air space of a clod of any shape by filling its pores with a hydrocarbon oil, such as paraffin or tetralin, and determining its weight in the oil and in air before and after impregnation. The method appears to work well for clods of any moisture content.

This method is shown to give values of these volumes entirely comparable with those given by the other accurate methods described in the literature.

Its accuracy for clods of Rothamsted soil, weighing between 20 and 500 g. was probably 1 part per thousand, i.e., 0·1 per cent.

The method has been applied to the determination of the available water held by a soil and has been used to illustrate the effect of long-continued applications of farmyard manure to a soil in increasing the amount of available water it can hold.

27. Russell, E. W. 1943. *The sub-division of the clay fraction in mechanical analysis.* J. Agric. Sci., **33**, 147-154.

An examination has been made of the possibility of extending the routine mechanical analysis of soils down to finer particles than the conventional clay. The main conclusions reached are :

(1) Sampling depths of only 2 cm., using standard mechanical analysis apparatus, appear to introduce no new sources of error.

(2) If a constant temperature room is available, sampling times of 7 days seem to be allowable.

(3) Using special pipettes and settling vessels, sampling depths of only 2½ mm. seem to be allowable.

(4) The amount of caustic soda to be added to a soil for proper dispersion depends on the soil, and this dependence limits the accuracy with which the mechanical analysis of the clay fraction can be carried out. There are no certain criteria available for deciding how much should be added, though Robinson's suggested 8 c.c. of N. NaOH per 20 g. of soil dispersed in 1 litre is probably rather too high for most English soils.

(5) Robinson's suggestion that the settling velocities of particles rather than their conventional size should be used has been adopted, and the symbol $pv = -\log v$ has been used throughout the paper.

(6) Routine mechanical analysis can be extended, by the simple methods here described, to clay particles with a conventional diameter of about 0·1μ.

28. Schofield, R. K. 1940. *Clay mineral structures and their physical significance.* Trans. Brit. Ceram. Soc., **39**, 147-161.

It is shown how the atomic structure of the clay minerals as revealed by X-ray analysis accounts for the presence of positively and negatively charged zones on the crystals. Measurements of ionic retention enable these charges to be measured and their variations with pH studied. In the presence of sufficiently concentrated salt solutions cations and anions are retained in equivalent amounts. Firmness of binding varies widely amongst both cations and anions. Support is found for the view that a network tends to form in clay suspensions through attraction between the positive and negative zones of neighbouring crystals. It is suggested that a condition in which the cations and anions leave equal amounts of positive and negative charge " uncovered " is particularly favourable for the formation of a network.

29. Saric, S. P. and Schofield, R. K. 1946. *The dissociation constants of the carboxyl and hydroxyl groups in some insoluble and sol-forming polysaccharides.* Proc. Roy. Soc. A., **185**, 431-447.

In order to establish the conditions under which the buffering of insoluble substance may most usefully be studied, suspensions of fibre cellulose, hemicellulose and xylan have been examined to determine the relationship between pH and the degree of dissociation of their carboxyl groups The materials were suspended in normal potassium chloride solution, in order to confine local gradients of hydrion concentration to the immediate vicinity of each charged buffer group. Under these conditions the dissociation curves are all of the simple Henderson type with a common constant $pK = 2{\cdot}95$ (N/100 hydrochloric acid in normal potassium chloride being taken as pH 2).

Sols of arabic and pectic acid follow the same dissociation curve, showing that the dissociation of the carboxyl groups is not necessarily influenced by the state of aggregation. Within the accuracy of these measurements, uronic and gluconic carboxyls have the same pK. The dissociation of pectic acid departs from the Henderson curve in the same general way as the dissociation curve of maleic acid differs from that of fumaric acid. It is suggested that some of the carboxyls in pectic acid are linked by hydrogen bridges. To a less extent such linkage may also occur in alginic acid below pH 3 when a gel is formed.

The *pK* for the first stage of acid dissociation of the hydroxyl groups in wheat starch is close to 13·3. The same value was obtained whether potassium hydroxide, calcium hydroxide or barium hydroxide was used. The alkalis were made up in normal solutions of the corresponding chlorides. The same constant holds for alginate within the limits of experimental error. The dissociation in cellulose up to pH 13·5 is much less than in starch.

Using a new method based on a determination of the ratio of chloride ions to hydroxyl ions, the dissociations of starch and cellulose were measured in 5 N. alkali (approximately pH 14·7). The second *pK* of starch is estimated at roughly 15·0. The cellulose, largely mercerized at this pH, exhibited a dissociation not much less than that of starch, and agreeing closely with the prediction of Neale.

An insoluble buffer substance suspended in an electrolyte solution is a two-phase system. The hydrion dissociation can be determined in two-phase systems over a greater pH range than is possible in one-phase systems.

30. Schofield, R. K. (1939). *The Lovibond Tintometer adapted by means of the Rothamsted device to measure colours on the C.I.E. system.* J. Sci. Instr., **16**, 74-80.

The Rothamsted device is an obturator vane by which the observer, when matching a specimen by a combination of Lovibond glasses, can make the two surfaces he is viewing look equally bright. This device greatly reduces the number of combinations required for colour matching. Conversion graphs give the C.I.E. co-ordinates for these combinations in Standard Illuminant B. The C.I.E. co-ordinates of matched colours are thereby obtained.

Other Papers

Keen, B. A. 1942. *Physical research on problems of soil cultivation.* Endeavour, **1**, 52-63.

Keen, B. A. 1942. *Agricultural research institutes and the future.* Nature, **150**, 282.

Keen, B. A. 1943. *Costings in agriculture.* Letter to *The Times*, May 3rd.

Schofield, R. K. and Scott Blair, G. W. 1943. *Bulb correction in capillary tube viscometry.* Nature, **152**, 477.

Russell, E. W. 1943. *Recent advances in soil physics.* Soils and Fertilizers, **6**, 47-51.

Keen, B. A. 1945. *Dry farming problems.* Nature, **155**, 529.

Russell, E. W. 1945. *Cultural functions of plough and hoe.* The Farmer's Weekly (South Africa), **69**, 1,150-1.

DEPARTMENT OF CHEMISTRY

By E. M. CROWTHER

GENERAL

During the years 1938 to 1941 several members of the Department were occupied with planning and equipping the new laboratories. The old ones were gutted and rebuilt to form a single compact unit with the new extension and part of the adjoining range of new glasshouses. The extra space made it possible to assign special rooms to spectroscopy, X-rays, micro-chemistry and the varied preparation and analytical work required for a rapidly expanding programme of field experiments. Some of the new laboratories could not be fully equipped during the war and were therefore used by other bodies, the A.R.C. Unit on Soil Metabolism and the British Leather Manufacturers' Research Association.

From 1940 onwards the programme of the Department was devoted increasingly to special investigations for the Agricultural Research Council, the Ministry of Agriculture and the Ministry of Supply, and to advisory work in connection with food-production problems. Much of this work was done in collaboration with other research institutes and the agricultural advisory service. It amounted in fact to what has become known as "operational research" or the collection of objective information by which current policies can be judged and improved. An early example of this type of investigation was the joint report from the Chemistry and Statistical Departments on the basis of a war-time fertiliser policy, described on page 262 of this Report. Much of this war-time work has not yet reached the stage at which results of more permanent and general interest can be worked up and published.

A great deal of the work has necessarily been carried out by teams with each individual specialising in one aspect. Those responsible for the main sections have been :—

R. G. Warren	Analyses and general supervision.
H. V. Garner	Field experiments away from Rothamsted."
G. Nagelschmidt	X-rays and mineralogy, and phosphate fertilisers in pot and laboratory experiments.
J. B. Hale	Spectrographic analyses.
G. W. Cooke	Soil phosphates and field experiments on phosphate fertilisers.
S. G. Heintze	Soil manganese and laboratory tests on availability of nitrogen fertilisers.
A. H. Bunting	Field experiments on organic manures and composts.
N. S. Bamji	Nitrification and fermentation tests.
E. H. Cooke	Pot experiments.
B. Benzian	Records and correlation of data.
H. Nixon	Phosphate and fluorine analyses.
Others who have joined the Department more recently are :	
W. E. Chambers	Spectrographic analyses of wheat straws from Broadbalk plots.
J. M. Bremner	Soil organic matter.
P. W. Arnold	Basic calcium-phosphate equilibria.

SOIL-FERTILITY PROBLEMS

During the war the laboratory work has been very closely linked with field and pot investigations. Nearly all of the field experiments provide soil, manure and crop samples which have been examined

partly to supplement the yield data by bringing out changes in crop quality and recovery of added nutrients, and partly to test the validity of laboratory methods in advisory work against the actual behaviour of field crops under a variety of soil conditions. It is anticipated that soil samples from many of the field experiments will be used for several years to come in checking and developing improved methods for soil analyses that may emerge from future laboratory investigations on more theoretical points.

The largest series of comparable soil samples from fertiliser experiments is provided by those on sugar beet carried out annually since 1933 for the Committee on Sugar Beet Education and Research, in collaboration with the agriculturists of the 17 sugar-beet factories in Britain. Several alternative methods for estimating readily soluble phosphate and potash (and some other elements) have been compared with the actual crop responses to various fertiliser combinations over a long period and a wide variety of soil conditions. It has become possible to define more closely the range of conditions with which current methods and some alternative ones may be used with fair confidence on soils of average fertility. The following figures illustrate the value of the citric-acid method which is widely used in advisory work. They give the average responses to standard dressings of superphosphate or muriate of potash in soils grouped by the results of analyses on samples taken before the manures were applied (the tests on phosphate are limited to non-calcareous soils and the responses to potash are in the presence of basal dressings of sulphate of ammonia).

Average responses in cwt. of extra sugar per acre in soils grouped by citric-acid analyses

P_2O_5 in soil, mg.%	No. of centres	Mean response to superphosphate	K_2O in soil mg.%	No. of centres	Mean response to muriate of potash
to 8	76	8·2	to 8	112	4·4
8·1—16	31	3·1	8·1—12	57	2·2
16·1—32	72	1·5	12·1—16	22	0·3
32·1—64	62	1·1	Over 16	20	0·0
Over 64	13	0·4			

There would clearly be a great economy if the practical manuring of such soils could be adjusted more closely to the indications from soil analyses. There is, however, room for great improvement in the analytical methods themselves, for discrepancies between expectation and performance are not uncommon. Some improvements are possible by recognising the limitations in the actual methods. Thus, for phosphate the citric-acid method is unsatisfactory for very acid soils and fairly good for calcareous soils, provided extra acid is used, whereas leaching with acetic acid is good for acid soils but not for highly calcareous ones. When such limitations are recognised there is a wide choice of alternative methods, some of which can be carried out quite rapidly, provided the technique of extraction and analysis is most rigidly standardised. Rough uncritical soil analyses may be most seriously misleading.

Pot cultures provide a useful but limited intermediate stage between laboratory and field experiments. Much time has been devoted to developing a rapid small-scale pot test for available nutri-

ents, especially phosphates, in soils, fertilisers and manures. This test proved particularly serviceable for various war-time fertilisers for which there was little or no previous experience in this country. One such class of materials was examined quickly and repeatedly as the scale of production expanded from the first few grams of a laboratory preparation through two stages of pilot plant to full commercial production. The problem of maintaining sufficiently constant moisture contents in small pots was solved by allowing glass pots to stand in saucers kept partly filled with water and using a mixture of soil with coarsely crushed flint to provide sufficient aeration. Radishes were generally used as the test crop, and after about four weeks were weighed, dried and ashed for phosphate analyses to determine the total uptake.

The small-pot technique has been used to estimate the available-nutrient contents of soils by measuring responses to added nutrients. It has not so far proved satisfactory for investigations on the difficult problem of phosphate fixation, perhaps because it fails to allow sufficiently intimate reactions between soil and fertiliser or because the soils remain continuously moist. Experiments on phosphate fixation are therefore being made with undiluted soil in larger pots testing a variety of phosphates in two contrasted soils by a series of successive crops of rape or cuttings of perennial ryegrass.

In laboratory studies on the availability of soil phosphates and the fate of added phosphates attempts have been made (13 to 17) to fractionate soil phosphate by successive extractions with such reagents as a weak acid, an alkali (followed by a differentiation between organic and inorganic forms) and a strong acid. This gives at least roughly a distinction between calcium phosphates, organic phosphates, iron phosphates and apatites. Extractions by dilute acids are sometimes complicated by secondary reactions by which dissolved phosphate recombines with or is absorbed by other soil constituents. Attempts have been made with some success to limit the extent of this disturbance by adding such materials as 8—hydroxyquinoline or selenious acid to the acids used in extracting the calcium phosphate.

Calcareous soils present special problems in using phosphate fertilisers and in assessing phosphate requirements. Soluble phosphates may react with calcium carbonate. Limestones or chalk may contain appreciable quantities of phosphate not immediately available to plants and yet brought into solution by excess acid in laboratory tests. It has recently been found (12) that the remaining chalk fragments in some of the Broadbalk soils receiving superphosphate contain appreciable amounts of fluorapatite, formed mainly during the last 50 years when the superphosphate has been made from mineral phosphate containing fluorine. Such a formation of fluorapatite in calcareous soils has long been expected on theoretical grounds, but this is the first direct experimental proof of its actual occurrence. One practical indication from studying the reactions likely to occur in calcareous soils is that soluble phosphates might well be given in small annual dressings, where possible close to the seed, and not in occasional heavy dressings intended to build up reserves.

At the other end of the scale of reaction attempts have been made to see what amounts of available phosphate are mobilised by liming very acid soils. These appear to be comparable with those in ordinary fertiliser dressings for land which has been manured in the past, but small for reclaimed waste land.

Organic manures

The general question of the part played by soil organic matter and bulky organic manures in the maintenance of soil fertility has remained in the forefront of our programme (2, 3, 35). During the war special attention was given to using both farm and town wastes to best advantage. The results of the experiments at Rothamsted are briefly summarised in the report on "Field Experiments on the Rothamsted Farm."

The experimental batches of farmyard manure made in bullock boxes and open yards were analysed to follow the fate of the nutrients, and the crops grown with them were also analysed to determine the ultimate recovery of the plant foods from the original feeding stuffs. All the materials used in the Rothamsted potato experiments and in a number of the other field experiments were tested in pot experiments in collaboration with the Botany Department and in laboratory nitrification and fermentation tests. Apart from supplying plant foods the farmyard manures and other fibrous manures have a definite physical effect which often appears to depend on maintaining a spongy open structure in the vicinity of the potato tubers.

Throughout the war a steadily increasing number of field experiments was carried out in different parts of the country under the auspices of a Conference of the Agricultural Research Council and often in collaboration with members of the Institute of Sewage Purification (4, 5, 6, 39). Before the agricultural quality of town refuse necessarily deteriorated with improving salvage, a number of experiments had shown that its manurial value was too low to justify appreciable expenditure on transport and application. Sewage sludges used alone or in composts with straw offered much more promise, essentially as sources of slowly available nitrogen and phosphate. Their poverty in potash must be recognised if seriously unbalanced manuring is to be avoided. The availability of the phosphate varied widely, low values commonly occurring in sewage sludges with large amounts of iron and other heavy metals from industrial wastes. Digested sludges have not only better physical conditions, but more readily available nitrogen than raw sludges. Shed-dried ground sludges are naturally more convenient to handle and are richer in immediately available nitrogen. Some of them have given poor results when applied in potato bouts, and it is not yet clear whether this is due to toxic elements or to providing too high local concentrations of ammonia near the sets. In most of the experiments the amounts of available nitrogen and phosphate accounted for the observed benefit : indications of physical improvements were obtained only after repeated heavy dressings. Composts of sewage sludge and straw have shown additional advantages which must be ascribed to physical improvements in the soil and to the supply of useful amounts of potash. In 1945 this range of field

experiment was extended so as to test sludge-straw composts and straw ploughed-in with sulphate of ammonia over a wide range of soils, including some thin soils over chalk, so as to provide extreme contrasts with the older Rothamsted experiments.

Most of the experiments on bulky organic manures have been of a complex design testing the various combinations of N, P, K fertilisers in conjunction with each organic manure and also without organic manure. Many of the experiments have been on market-garden soils for which additional supplies of organic manures are so much needed.

An important section of this work has been the laboratory study of the content and availability of the nutrients, especially nitrogen, in different kinds of farmyard and other bulky manures. A large mass of analytical data has shown the average composition and range of variation of bulky organic manures produced under different conditions. The field experiments have brought out several instances in which practical judgments of the stage of rotting and manurial value of farmyard manures differed markedly from their performances in the field. The phosphate and potash contents frequently provided the clue. Some indication of the availability of nitrogen and the stage of rotting or maturity was obtained from a new fermentation test based on the effects of added cellulose or ammonium nitrate on the carbon-dioxide production under controlled conditions.

Fertilisers

Slowly acting nitrogen fertilisers such as hoof-and-horn were difficult to obtain during the war and various alternatives were investigated. One very slowly acting but none the less active material was found in formalised casein, a plastic waste. This decomposes in the soil much more slowly than hoof-and-horn of normal grist, and for this reason its value was not at first realised in practice. It should have merit as a basal dressing where a succession of crops is to be taken. It serves to provide an interesting contrast with the more rapidly available forms, such as dried blood and fine hoof meal, in trials on rate of action of nitrogenous fertilisers.

Ground leather waste has negligible value as a fertiliser. Our experiments have shown that some of the commercially treated leather wastes prepared by acid digestion have only a modest fraction of their nitrogen in a rapidly available form and very little in slowly available forms. In collaboration with the British Leather Manufacturers' Research Association attempts were therefore made to find other ways of converting waste leather into a useful fertiliser by detanning vegetable-tanned leather to free the hide protein. It was shown by laboratory tests, by pot-culture experiments in collaboration with the Botany Department and by field experiments on market-garden crops that the product was comparable in activity with dried blood or crushed hoof. Unfortunately it did not prove possible during the war to put the process into production on the commercial scale.

The choice of phosphate fertilisers is rapidly being widened as the result of promising new developments in chemical engineering. New concentrated soluble phosphates, triple superphosphate and a

granulated form of ammonium phosphate proved popular during the war. An entirely new range of insoluble but highly available phosphates is steadily being developed, especially in the United States. Under some conditions considerable economy can be effected by using relatively cheap mineral phosphates in place of more elaborately treated products. There are still great possibilities in improving the present low efficiency of phosphate fertilisers by adjusting the amounts, forms and methods of application more closely to the actual conditions of crop, soil, climate and farming system.

Some of these problems became urgent several times during the war when it seemed possible that one or both of the two imported ingredients of superphosphate—mineral phosphate and pyrites—might become scarce. Had sulphuric acid been short, it would have been necessary either to use mineral phosphates directly on suitable land or to convert them into more readily available fertilisers in some other way. Good results were obtained in experiments with Curacao mineral phosphate, a very hard material containing unusually little fluorine. Fortunately it was found unnecessary to grind it very finely. Both Curacao and Gafsa mineral phosphates gave excellent results for swedes on acid land in wet districts, especially in soils with very little phosphate soluble in dilute acetic acid. A novel American phosphate—calcium metaphosphate—with the equivalent of over 60 per cent. P_2O_5 acted very slowly but appeared to be well suited for leys and other crops occupying the land for long periods.

In collaboration with the Building Research Station of the D.S.I.R., investigations were carried out for the Ministry of Supply on preparing a readily available phosphate by sintering mineral phosphate with soda ash and sand in the presence of steam. Materials with high citric solubilities were shown to give good results in pot and field experiments. The product, which has been produced successfully on the full technical scale under the name "Silico-phosphate," compared very favourably with superphosphate containing equal amounts of phosphate for swedes and re-seeding in the wetter areas, but not for potatoes and cereals in drier ones.

Several series of laboratory, pot and field experiments showed that there was no reason under wartime conditions to vary our earlier conclusion that the citric-acid test provides a sound indication of the amounts of available phosphate in different kinds of basic slag. Those with little citric-soluble phosphoric acid should not be regarded as phosphate fertilisers, but as liming materials containing a little available phosphate. They may prove useful in heavy dressings for reseeding on very acid soils, but should not be used far from the works.

In a few field and pot experiments self-slaking or falling slags from blast furnaces and certain special steel furnaces proved almost as effective as limestone, and in addition increased the availability to crops of phosphates in the soil or added fertilisers.

Reverted mixtures of superphosphate and such basic materials as lime, basic slag and serpentine gave results closely similar to those from superphosphate supplying the same amount of phosphate. This result suggests that all the merits claimed for serpentine-superphosphate in New Zealand are not likely to be generally

obtained in Britain. It also adds one more piece of evidence for the view that the time has arrived for revising the methods adopted in the Fertiliser and Feeding Stuffs Act Regulations for expressing the solubility of phosphate fertilisers. The water-solubility test originally designed for distinguishing between good and bad samples of superphosphate can have little general validity when all superphosphates and ammonium phosphates are well made and when many other phosphate fertilisers containing little or no water-soluble phosphate are known to be as effective as superphosphate.

Combined fertiliser-grain drills imported during the war have demonstrated their value on many farms. Field trials on cereals carried out by Technical Development Sub-committees for an A.R.C. Conference showed that on the average 1½ cwt. of superphosphate per acre drilled with the seed were as good as 3 cwt. broadcast (10). Trials were made at Rothamsted and a few other Hertfordshire farms during 1945 on four different methods of applying a mixed fertiliser for potatoes, using a special experimental drill built by the National Institute of Agricultural Engineering. Apart from a slight and doubtful superiority at low rates of dressing of fertilisers placed in contact with the sets, there were negligible differences between the methods used.

Fertiliser requirements of crops

Sugar beet

The standard series of sugar-beet experiments carried out since 1934 has served to establish the general requirements of this crop for average soils and seasons and to show how special soil needs can be estimated by soil analyses (33). The average responses in 268 experiments on commercial farms, averaging over all combinations of other fertilisers were :—

	Washed roots	Tops	Sugar %	Cwt. sugar per acre
	Tons per acre			
0·8 cwt. N per acre as sulphate of ammonia ..	1·32	2·86	—0·40	3·8
1·0 cwt. P_2O_5 per acre as superphosphate	0·45	0·32	0·01	1·6
1·2 cwt. K_2O per acre as muriate of potash ..	0·44	0·26	0·22	2·0

The main need is for ample nitrogen with only moderate amounts of phosphate and potash.

The responses to nitrogen and potash together were greater than the sum of the separate responses, but those to superphosphate did not depend on the presence or absence of other fertilisers.

	Cwt. sugar per acre
Response to 4 cwt. sulphate of ammonia per acre ..	3·1
Response to 2 cwt. muriate of potash per acre ..	1·2
Response to both together	5·8

The standard series of experiments brought out marked seasonal differences in the behaviour and composition of the sugar-beet crop. Thus, the dry summer and wet autumn of 1944 were particularly unfavourable for sulphate of ammonia, whereas in the wet summers and dry autumns of 1936 and 1941 sulphate of ammonia gave particularly large average responses.

From 1940 onwards the design was modified to test in addition the effect of 5 cwt. of agricultural salt per acre (8, 9, 36, 43). The average results for the individual years and for the main classes of soils are summarised below for plots receiving nitrogen at the rate of 4 cwt. of sulphate of ammonia per acre. On the average of over 100 experiments 5 cwt. of salt gave 5 2 cwt. of additional sugar, whereas 2 cwt. of muriate of potash gave only 2.8 cwt. of additional sugar. Even where 2 cwt. of muriate of potash were given there was a further response of 2.6 cwt. of sugar for 5 cwt. of salt, but where salt was given there was a negligible additional response to potash.

Cwt. additional sugar per acre on sugar-beet plots receiving sulphate of ammonia

Average for all soils (except fens)	No. of trials	From muriate of potash alone	From salt alone	From muriate of potash and salt together
1940	24	3·5	5·4	6·1
1941	22	3·2	4·8	5·2
1942	21	3·4	5·0	5·8
1943	18	1·1	4·4	4·4
1944	18	2·4	6·4	5·2
Five years	103	2·8	5·2	5·4
Average for five years				
Coarse sands	20	2·8	5·4	6·4
Fine sands	19	4·7	5·7	6·5
Light loams	37	2·3	4·7	4·4
Heavy soils	27	2·2	5·3	5·2
Fen soils	9	2·4	2·3	3·8

Systematic analyses of samples of sugar-beet tops and roots showed that the larger crops grown with salt contained no more potash than those without salt. Considerable amounts of sodium are taken up from the salt, but only a very small amount of the sodium reaches the roots. This work has shown that sodium must be regarded as a true plant food for sugar beet (and mangolds), and that salt does not act by drawing on reserves of potash in the soil. Sugar-beet growers should use salt much more generally, even when supplies of potash are easier to obtain.

Special series of experiments have shown that the salt may be applied at any convenient time up to a week or two before sowing, even before the winter ploughing. Although the soil structure may be temporarily damaged by heavy rain after applying salt, there has been no evidence of any bad effect on the crop or any cumulative effect on the soil, even where, as in one Rothamsted experiment, salt is applied every year.

Borax was included in the series of experiments from 1945. In that season it had negligible effects.

Flax

In collaboration with H.M. Flax Establishment, Flitcham Abbey, Norfolk, and Advisory Chemists, a series of field experiments was carried out each year from 1940 to 1945 to test the effect of nitrogen, phosphate and potash fertilisers on the yield of processed flax. On the whole the crop proved relatively unresponsive. Even where the field weights of the crop showed responses to fertilisers the benefit often disappeared during processing. There is no justification for manuring flax differently from barley. Phosphate and potash are needed only on soils deficient in these plant foods.

Rubber

Some of the results of manurial experiments on young rubber plantations conducted since 1933 by Messrs. Dunlop Plantations in Malaya, in collaboration with Rothamsted, have been published (11). Mineral phosphate had spectacular effects on early growth, the trees reaching the tapping stage from six months to two years earlier, with a corresponding saving in the initial costs of getting an estate into bearing.

Oil palm

A somewhat similar series of manurial experiments was laid out on the oil-palm estates of Messrs. Unilever in Nigeria, and the Belgian Congo, from 1940 onwards, the plans being outlined and some of the sites selected during Dr. E. M. Crowther's tour in West Africa in 1938-39 (1). So far the trees already in bearing have given only modest responses, though this may have been due in part to wartime interruption in the manuring programme. Results for the young trees are not yet available.

Forest trees in nurseries

Under a programme of work drawn up by a Forestry Commission Committee on Nutritional Problems in Forest Nurseries, manurial experiments were laid out in 1945 on four nurseries and in boxes at Rothamsted. All the nursery experiments included Sitka spruce and ash, with Scots pine and birch in addition at one nursery. The preliminary indications from shoot growth in the first season are that much of the benefit from composts, especially in waste-land or woodland nurseries, can be ascribed to the plant nutrients they supply, and that some of the differences between nurseries can be interpreted in terms of the nutrient status of their soils as shown by soil analysis and by the responses to fertilisers. The indications are necessarily tentative as the experiments are to be continued through the lining-out stage and new experiments started in seedbeds in 1946. In box experiments with a slightly calcareous old nursery soil, on which Sitka spruce had consistently failed, large plants were grown on soil which had been acidified, the heights regularly following the amounts of acid added.

Soil manganese

Manganese deficiencies in such crops as oats, potatoes and sugar beet are fairly easily recognised by leaf symptoms and by the response of the crop to sprays containing manganese sulphate.

The deficiencies are known to be associated with certain types of soil, especially heavily limed soils rich in organic matter, but there is no satisfactory method of estimating available manganese in the soil. A variety of different soils including a series of pairs of samples representing contrasted crops in the same field was examined for different forms of manganese. The exchangeable manganese generally increased with soil acidity, but, except in some very acid soils, formed only a small fraction of the readily reducible manganese. The exchangeable manganese tended to be low where sensitive crops showed deficiency symptoms, but it was sometimes low where the crops were healthy. There was no evidence to support the view that the readily reducible manganese was a better guide than the exchangeable manganese. In some contrasted pairs of soils, mainly fens, with similar reactions and contents of exchangeable and total manganese, deficiency symptoms were shown on the soil with the higher content of nitrifiable nitrogen. Other evidence from field and pot experiments supported the view that high available nitrogen favours manganese-deficiency symptoms.

Manganese salts added to neutral or alkaline soils rapidly pass over from the exchangeable to other forms which are readily reducible and soluble in solutions of sodium hexametaphosphate. In the course of an attempt to fractionate organically bound manganese it was found that a large proportion of the soil manganese dissolves as a complexion in sodium hexametaphosphate. When the staff of the A.R.C. Unit of Soil Metabolism had established the importance of trivalent manganese in the soil, a critical examination was undertaken in collaboration with them on methods for determining the various forms of manganese in soils. Improved methods for determining di-, tri- and tetra-valent manganese were applied to contrasted soils without, however, finding any infallible criterion for manganese deficiency. In most deficient soils a high proportion of the total reducible manganese was in the manganic form.

Pot and field experiments on " marsh spot " in peas showed that direct application of manganese materials to the soil had erratic effects, owing to rapid oxidation. The critical period for the uptake of manganese proved to be from the flowering stage onwards. By injecting various inorganic nitrogen compounds and amino acids into plants it was possible to induce " marsh spot " in peas grown on soils amply supplied with available manganese. It was also found that oats in pot experiments on manganese-deficient soils developed severe " grey speck " when treated with sulphate of ammonia.

Spectrographic analyses

With the completion of the new extension in the autumn of 1939 it was possible to equip a basement room as a spectrographic laboratory complete with dark room. The installation consisted of a Hilger medium quartz spectrograph (fD 60 cm.) and non-recording microphotometer, with the necessary equipment for arc and spark methods and for the Lundegårdh air-acetylene flame method for analysing solutions.

In analysing plant material for the common elements by the flame method the preparation of hydrochloric-acid extracts of ash

was found to be too laborious, and a more convenient method avoiding ashing was developed from a brief statement by Terlikowski and Sozunski that hydrochloric acid extracts all the potassium, sodium, calcium and magnesium from dried ground plant material. The extraction of calcium was not quite complete, but all the manganese was extractable. In the standardised method 1.25 g. of dried ground material are extracted by 50 ml. of N.HCl for 24 hours with occasional stirring. Tenfold dilution of this extract is needed for potassium and the higher ranges of sodium and magnesium and further dilution for calcium.

Boron is determined by the copper arc, the plant ash being mixed with an equal weight of a mixture of sodium chloride and ammonium sulphate containing 1 per cent. of tin as an internal standard. A plate-blackening trace is applied to every plate and a correction made for blackening of the spectral background. Other undetected sources of error may still remain. The standard error of the mean of two determinations on the same ash sample is about 9 per cent.

The Lundegardh method as adopted for the analysis of plant material has been found extremely useful in diagnosing mineral deficiencies in crops and in following the uptake of nutrients in field experiments. Since 1940 a considerable amount of work has been done in helping Advisory Chemists in the diagnosis of plant diseases. In cooperation with Dr. R. Hull of the Midland Agricultural College and Dr. Marion Watson of the Rothamsted Plant Pathology Department, sugar-beet diseases have been studied both by means of field experiments and by analysing samples from many different localities. Deficiencies of magnesium, manganese and boron and ones due to potassium and or sodium can now be recognised and distinguished from each other and from chlorosis of the foliage due to virus and fungus diseases. On some acid soils chlorosis is accompanied by excess manganese in the leaves.

The technique of sampling field experiments during the growing season to obtain representative samples was studied in 1940 and 1941 for potatoes and sugar beet. Every year since then samples of leaves and roots from nearly all the main series of sugar-beet manurial experiments have been analysed to study the function of salt in the manuring of sugar beet and the role of sodium in the plant. To obtain more information on these questions series of whole-plant samples were taken in collaboration with Dr. D. J. Watson at three-weekly intervals from all plots in the Rothamsted two-course rotation experiment during 1942 and 1943. Plant weights and leaf areas were taken on each occasion and the samples analysed for nitrogen, potassium, sodium, calcium, magnesium and manganese.

A considerable number of analyses have been made on leaves from Nigerian oil palms showing various "yellowing" diseases, and some evidence obtained of potassium and magnesium deficiencies.

Soil mineralogy

The chief object of this section of the work was to develop methods for a quantitative determination of the various minerals in the clay fractions of soils, and to use them for the study of

typical soil profiles. In a critical review (19) of the results obtained by 1939, it was shown that it was essential in determining clay minerals to use combinations of X-ray, optical and chemical methods. One example of this approach to problems of soil formation was given in a detailed study (21) of two Indian soil profiles. It was shown that contrasted clays can be produced from the same parent material under different topographical conditions, with kaolin as the chief constituent under eluvial and montmorillonite under illuvial conditions. Work on other tropical soils from the Sudan, India and West Africa was interrupted by the war. As a preparation for further work in this field, existing information on the mineralogy of soil colloids was reviewed in 1944 in a Technical Communication of the Imperial Bureau of Soil Science (20).

The same technique for studying clay minerals was used in work conducted for the Medical Research Council's Enquiry into Pulmonary Disease in South Wales Coalminers (24-30). The mineralogical composition and sources of airborne dusts and composition of lung residues of miners who had suffered from pneumokoniosis were studied, and the results correlated with medical, environmental and pathological work.

Analytical methods

The large number of soil, fertiliser and crop samples taken in connection with the field and pot experiments in the work described above made heavy demands on the analytical staff of the Department. Whenever moderate accuracy will suffice rapid colorimetric or turbidimetric methods have been developed. Thus, in the small pot experiments the radishes from single pots or from bulked replicate pots are burnt with alcoholic magnesium nitrate and ashed, and the phosphoric acid determined colorimetrically by the Hilger Absorptiometer. Other crops and bulky organic manures are digested with sulphuric and nitric acids, and the phosphate determined colorimetrically. Approximate determinations of potash in crops, manures and extracts of soils are made turbidimetrically by the cobaltinitrite method.

Where less acuracy will suffice, colorimetric and turbidimetric determinations are made visually for phosphate, potassium and magnesium. In plant samples from field plots and for checking visual diagnoses of deficiency symptoms, comparisons have been made between the total contents of these nutrients and the amounts brought out in " tissue-testing." With Morgan's reagent (sodium acetate and acetic acid) the amounts of phosphate and potash extracted increased steadily up to two hours. Normal hydrochloric acid extracted the potash more rapidly and completely.

Nitrates and ammonia in soils are determined by extracting with an acid salt solution and determining ammonia before and after reduction with reduced iron using either the Conway aeration unit or the micro-Kjeldahl method for the ammonia.

Methods have been developed for determining fluorine in fertilisers and some progress made with a micro-method for use on soils.

PUBLICATIONS

SOIL FERTILITY AND MANURING

1. SAMPSON, H. C. and CROWTHER, E. M. 1943. *Crop production and soil fertility problems.* The West Africa Commission 1938-1939 Technical Reports, Leverhulme Trust, 8-58.

This report on one section of the agricultural problems of the British West African colonies was prepared by two of the technical experts who accompanied a Commission of four members of Parliament on a tour of all the British and French colonies in West Africa during the winter of 1938-9. It describes the main climatic, geographical and soil conditions, the characters and origins of the principal crops and the main types of West African agriculture, including the special problem of plantations in West Africa. It discusses the administrative and investigational work of the several Departments of Agriculture and the agricultural problems arising in the activities of other Departments. Proposals are advanced for a post-war reorganisation of scientific research and survey, with special emphasis on ecological and soil surveys, meteorology, field experiments on crop rotations and the maintenance and improvement of soil fertility.

2. CROWTHER, E. M. 1943. *The maintenance of soil fertility.* J. Roy. Soc. Arts., **91**, 431-437. Reprinted in The American Fertilizer, **99**, No. 12; and Agriculture—Today and Tomorrow, edited by Sir John Russell; and in abridged form in Agriculture, **50**, 262-264.

A general discussion of the scientific and practical problems involved in the maintenance of soil fertility, with special reference to the role of soil organic matter and plant roots in the formation and conservation of soils, the rotation of crops, and the supply of available nutrients.

3. CROWTHER, E. M. 1942. *Straw on the land.* J. Min. Agric., **49**, 146-150.

The practical problems involved in utilising local war-time surpluses of straw are discussed in relation to the nutrient contents of straw, the physical effects of straw manures, the preparation of composts and direct ploughing-in. On the average the straw crop from one acre contains about as much potash as 1 cwt. of muriate of potash, but on potash-deficient soils the straw supplies much less potash. Results of a Rothamsted rotation experiment since 1934 showed that straw and a fixed quantity of fertilisers gave the best results when the straw was ploughed-in during the autumn and fertilisers applied directly to the following potato crop. The immediate effect from composting the straw and fertilisers was less than using the fertilisers alone. In the second year there was moderate residual effect from each method of using straw. There was little or no immediate or residual effect of straw in either form on sugar beet or barley.

4. CROWTHER, E. M. 1943. *Composts, their preparation and value.* Ann. Appl. Biol., **30**, 392-395.

A general review.

5. CROWTHER, E. M. and BUNTING, A. H. 1942. *The manurial value of sewage sludges.* Annual Summer Meeting, July 9th and 10th, 1942, J. Inst. Sewage Purif. 13-25.

The history of investigations into the agricultural use of sewage and sewage sludges is summarised in relation to modern views on the part of soil organic matter and plant foods in the maintenance of soil fertility. The principal types of current sewage sludges are described. The results of preliminary pot and field experiments on representative sewage sludges are briefly presented.

6. CROWTHER, E. M. and BUNTING, A. H. 1944. *The manurial value of sewage sludges.* Part 2. Presented at Annual General Meeting, Midland Institute, Birmingham. 6th and 7th December, 1944. J. Inst. Sewage Purif., 46-52.

A review of the results of recent field and pot experiments on different kinds of sewage sludge, with analytical data for the average chemical com-

positions of sewage sludges grouped according to the principal processes used at the sewage works. Although some sewage sludges supplied considerable amounts of readily available nitrogen and phosphate, a few others were singularly inactive in field experiments on potatoes. Digested sewage sludges have not only better physical properties but supply more available nitrogen than raw sludges. Shed-dried sludges hold out considerable promise, especially where they can be prepared from sewage without unduly high contents of heavy metals and other industrial wastes.

7. Russell, E. J. and Garner, H. V. 1941. *Rothamsted experiments on the manuring of potatoes.* Emp. J. Exp. Agric., **9**, Part I : 195-215. Parts II and III : 217-235.

The results of experiments carried out at Rothamsted and its outside centres from 1921-1940 are discussed. Sulphate of ammonia was usually very effective on a wide range of soils. The mean increase was at the rate of 0·92 tons of potatoes for 0·25 cwt. of N per acre. Nitrogen gave practically the same increase in the presence as in the absence of dung, and the nitrogen response was usually greater in the presence of phosphate and also in the presence of potash. None of the other sources of nitrogen included in the experiments, calcium cyanamide, ammonium bicarbonate, ammonium chloride was as effective as sulphate of ammonia. Superphosphate was less consistent in its action than sulphate of ammonia, the increases ranging from 0·4 to 1·9 tons for 0·5 cwt. of P_2O_5 per acre according to soil type. It did best on the fenland soils and the heavier type of mineral soils. The phosphate responses in presence of dung were on the average little more than half those observed in the absence of dung. Gafsa phosphate was ineffective on potatoes at Rothamsted.

Potash responses depended on the state of fertility of the soils, rich well-farmed soils giving high basal yields and low responses to potash, poor soils giving as a rule handsome responses. Light fenland soils, and the heavy loam at Rothamsted were highly responsive to potash dressings. Dung reduced the potash responses by approximately 80 per cent.

Magnesium sulphate was ineffective at practically all centres at which it was tried. Chloride, applied as ammonium, sodium or potassium chloride had a slight and rather consistent depressing effect on yield amounting on the average to a loss of 5 cwt. of potatoes per 1 cwt. of Cl supplied in the manure.

Farmyard manure and potassic fertilisers markedly increased the percentage of saleable tubers.

8. Crowther, E. M. and Garner, H. V. 1940. *Potash and potash substitutes for sugar beet.* Sugar Beet Rev., **13**, 248-250.

A summary of the results of pre-war field experiments in which promising results had been obtained from agricultural salt.

9. Crowther, E. M. 1943. *Worth its weight in sugar.* Farmers Weekly, **18**, No. 15, 29.

A summary of the results of field experiments over several seasons in each sugar beet factory area of Great Britain in which it was found that agricultural salt at the rate of 5 cwt. per acre gave on the average about its own weight of additional sugar. This extra crop is obtained without any increased drain on the potash reserves of the soil. The increased crops given by salt contain no more potassium but much more sodium than those grown without salt. Sugar beet and mangolds are among the few cultivated crops for which sodium is a true plant food.

10. Crowther, E. M. 1945. *Combine-drilling of phosphate fertilisers for cereals.* Agriculture, **52**, 170-173.

The average results of 46 trials by Technical Development Sub-Committees during 1943 and 1944 showed that 1½ cwt. superphosphate per acre drilled with the seed was as effective as 3 cwt. broadcast.

11. Haines, W. B. and Crowther, E. M. 1940. *Manuring Hevea.* III. *Results on young buddings in British Malaya.* Emp. J. Exp. Agric., **8**, 170-184.

The results of fourteen manuring experiments with young budded rubber laid down in 1934 on the Dunlop rubber estates in Malaya are described.

The experiments tested sulphate of ammonia, mineral phosphate and muriate of potash each at three levels in a 3 x 3 x 3 design, with individual plots of 3 experimental rows half a mile long with a pair of similarly treated guard rows. Each set of five fertilised plots was separated from the next set by an unmanured row. The set of experiments occupied 1,260 acres, exclusive of guard rows.

Phosphate proved to be the outstanding stimulant of growth, earlier maturity to the extent of between 6 months and 2 years being gained where the manuring was started early in the life of the trees. Nitrogen gave much smaller effects, and potash normally gave nothing measurable. Interactions between fertilisers were not of great importance. The yields of latex per tree in early tapping years gave very small differences in comparison with the great influence of phosphate on vigour and growth as shown in the number of trees fit for tapping.

SOIL PHOSPHATES

12. Nagelschmidt, G. and Nixon, H. L. 1944. *Formation of apatite from superphosphate in the soil.* Nature, **154,** 428.

Chalk fragments from Broadbalk plots which had received superphosphate for a century contain up to 3 per cent. P_2O_5. X-ray diffraction data before and after heating suggest that the phosphorus is present as apatite. Examination of old soil samples showed that both phosphorus and fluorine contents increased steadily with time, at first slowly when the superphosphate was made from bone ash, and much more rapidly since 1888 when the superphosphate has been made from mineral phosphate, relatively rich in fluorine.

13. Ghani, M. O. 1941. *Fractionation of phosphoric acid in organic manures.* Indian J. Agric. Sci., **11,** 954-958.

The distribution of the principal forms of phosphorus compounds were determined in poultry manure, farmyard manure and straw compost, prepared by the Adco process. A large part of the phosphorus in poultry manure was present as phytin, but three-quarters of the total in farmyard manure was inorganic, mostly in an easily soluble form. Classical plots at Rothamsted and Woburn gave high values for both acetic acid-soluble and organic phosphorus where farmyard manure had been applied repeatedly.

14. Ghani, M. O. 1942. *Determination of organic phosphorus in alkali extracts of soils.* Indian J. Agric. Sci., **12,** 336-339.

In colorimetric determinations of inorganic and organic phosphorus in alkali extracts of soils, oxidation of organic matter by bromine at 100° breaks down a part of the organic phosphorus compounds, but oxidation at room temperature does not.

15. Ghani, M. O. 1943. *Fractionation of soil phosphorus. I. Method of extraction.* Indian J. Agric. Sci., **13,** 29-45.

Earlier work by L. A. Dean (J. Agric. Sci. 1938, **28,** 234) on extracting phosphorus by successive treatments with a weak acid, an alkali and a strong acid was critically examined and extended. N/2 acetic acid was used for the preliminary removal of exchangeable bases and as a solvent for readily soluble phosphorus. Sodium hydroxide extracted more phosphorus than sodium carbonate at equivalent concentrations. Alkali extraction at 100° dissolved more phosphorus than at 20° or 40° but organic phosphorus compounds were partly decomposed. Several extractions were necessary to dissolve the whole of the soluble phosphorus at room temperature, and a suitable porous candle filtering apparatus was therefore devised for repeated extractions. 2N sulphuric acid after the alkali treatment was suggested for removing the apatite fraction. See also Part II. *Chemical nature of the phosphorus fractions* by M. O. Ghani and S. A. Alekm, 1943, *ibid,* **13,** 142-147.

16. Ghani, M. O. 1944. *Fractionation of soil phosphorus. III. The organic phosphorus fraction.* Indian J. Agric. Sci., **14,** 261-267.

An alkali extraction method and an ignition method for determining organic phosphorus gave fairly concordant results, except in fen soils. With suitable modifications to meet the special conditions of these soils the two methods gave comparable results. The hydrogen peroxide method for determining organic phosphorus was found to have serious limitations.

17. GHANI, M. O. 1943. *The use of 8-hydroxyquinoline as a means of blocking active iron and aluminium in the determination of available phosphoric acid of soils by dilute acid extractions.* Indian J. Agric. Sci. **13**, 564-565.

8-hydroxyquinoline was used to deactivate free sesquioxides during acid extraction of soils. It prevented refixation of phosphorus dissolved by acetic acid from a mixture of basic iron phosphate and mineral phosphate, and increased the amount of phosphorus extracted by acetic acid, especially from acid lateritic soils.

MINERALOGY OF SOIL COLLOIDS

18. RAYCHAUDHURI, S. P. 1941. *Studies of the physico-chemical properties of associated black and red soils of Nyasaland Protectorate.* Indian J. Agric. Sci., **11**, 100-109.

Detailed physico-chemical studies were made on a typical pair of closely adjacent red and black soil profiles from Domira Bay, Nyasaland. The silica-alumina and silica-sesquioxides in the clay fractions were only slightly lower in the red soils. The free sesquioxides by Truog's method were higher in the clay fractions from the red soils. The black soils had only a little more total carbon but appreciably higher C/N ratios than the red soils at similar depths. The black soils had much higher exchangeable bases, buffer capacities, moisture equivalents and imbibitional moisture capacities than the red soils, although the two types had nearly the same clay contents

19. NAGELSCHMIDT, G. 1939. *The identification of minerals in soil colloids.* J. Agric. Sci., **29**, 477-501.

X-ray, optical, dehydration and chemical methods in use for the identification of minerals in soil colloids are discussed with special regard to their limitations. These are mainly due to uncertainties about the variation of physical properties of standard minerals with decreasing grain size and the possible existence and importance of amorphous material. The aggregate method in X-ray analysis, which is specially important for soil colloids, is described. Various techniques for dehydration and optical analysis are discussed, and it is concluded that they are useful only when used in combination with X-ray data. The advantages of combining various chemical methods with X-ray analysis are pointed out.

Standard data are given for a number of minerals, and the evidence for their occurrence in soil colloids is reviewed. These minerals are quartz, cristobalite, oxides and hydroxides of iron and aluminium, minerals of the kaolinite, montmorillonite and mica groups.

20. NAGELSCHMIDT, G. 1944. *The mineralogy of soil colloids.* Imp. Bur. Soil Sci. Tech. Commun., **42**, pp. 43.

A critical review of the literature with bibliography.

21. NAGELSCHMIDT, G., DESAI, A. D. and MUIR, A. 1940. *The minerals in the clay fractions of a black cotton soil and a red earth from Hyderabad, Deccan State, India.* J. Agric. Sci., **30**, 639-653.

The mineral compositions of the clays from a red earth and a black cotton soil from Hyderabad, Deccan State, India, occurring in close proximity in the field are determined. Both soils are derived from the same or from very similar parent rocks, a coarsely crystalline granite or gneiss.

For both soils there is practically no variation in the mineralogical composition of the clay throughout the profile, but for any given clay there is some variation with grain size. The main contrast between the two is that the red clay contains predominantly kaolinite or halloysite whereas the black clay contains mainly beidellite, a member of the montmorillonite group The topography appears to be the principal factor associated with this difference in minerals, and the processes of weathering believed to have produced the contrasted clays are discussed with reference to experiments on the leaching of felspar in the laboratory and on hydrothermal synthesis.

22. NAGELSCHMIDT, G. 1941. *The identification of clay minerals by means of aggregate X-ray diffraction diagrams.* J. Sci. Inst., **18**, 100–101.

23. NAGELSCHMIDT, G. 1944. *X-ray diffraction experiments on illite and bravaisite.* Min. Mag., **27**, 59-61.

One sample of illite and a fresh glauconite showed no change in basal spacing on saturation with calcium. Two illites from Illinois showed a small but distinct broadening of the basal reflection towards larger spacings on saturation with calcium. Although illite may be assumed to have a basal spacing of 10 A, there may be intermediate products of weathering in which 10 and 15 A packets are interstratified in various ways.

MINERALOGY OF AIR-BORNE DUSTS AND COALS

24. NAGELSCHMIDT, G. and KING, E. J. 1941. *The biochemistry of silicic acid. 9. Isolation and identification of minerals in lung residues and air-borne dusts from coal mines.* Biochem. J., **35**, 152-158.

25. NAGELSCHMIDT, G. and HICKS, D. 1943. *The mica of certain coal-measure shales in South Wales.* Min. Mag., **26**, 297-303.

26. NAGELSCHMIDT, G. and HICKS, D. 1943. *X-ray diffraction technique for the identification of non-coal minerals in coal.* Proceedings of a Conference on the ultra-fine structure of coals and cokes, B.C.U.R.A. London, June 1943.

27. NAGELSCHMIDT, G. 1943. *Chronic pulmonary disease in South Wales coalminers. II. Environmental studies. D. The composition of the air-borne dusts at the coal-face in certain mines.* Special Report Series No. 244 (Medical Research Council) published by H.M. Stationery Office, 95-124.

28. HICKS, D. and NAGELSCHMIDT, G. 1943. *Chronic pulmonary disease in South Wales coalminers. II. Environmental studies. F. The chemical and X-ray diffraction analysis of the roof and clod of some South Wales seams, and of the mineral matter in the coal.* Special Report Series No. 244 (Medical Research Council) published by H.M. Stationery Office, 153-186.

29. HICKS, D. and NAGELSCHMIDT, G. 1943. *Chronic pulmonary disease in South Wales coalminers.* Appendix II. *The composition of the dust in the run-of-mine coal.* Special Report Series No. 244 (Medical Research Council) published by H.M. Stationery Office, 218-222.

30. KING, E. J. and NAGELSCHMIDT, G. 1945. *Chronic pulmonary disease in South Wales coalminers. III. Experimental studies. B. The mineral content of the lungs of workers from the South Wales coalfield.* Special Report Series, No. 250. Chronic Pulmonary Diseases in South Wales Coalminers, Part III (Medical Research Council), published by H.M. Stationery Office, 1-20.

GENERAL

31. OLDERSHAW, A. W. and GARNER, H. V. 1942. *Tunstall experiments with carbonate of lime.* Agriculture, **49**, 37-39.

A summary of the first 10 years' results on a replicated experiment on the acid soil (pH 4·9) at Tunstall, Suffolk, showing the exhaustion of ground chalk applied at 4 levels in 1932. Excellent yields were obtained, but definite deterioration of the plots receiving only 1 ton of carbonate per acre were apparent towards the end of the period.

32. OLDERSHAW, A. W. and GARNER, H. V. 1944. *Light land experiments at Tunstall, Suffolk.* J.R.A.S.E., **105**, 98-114.

An account of the Tunstall experiments since their commencement in 1925. The results include replicate experiments on potatoes and carrots, testing dung and its interactions with mineral fertilisers.

33. GARNER, H. V. 1944. *The war-time manuring of sugar beet.* Farmers Weekly, August 1944.

34. GARNER, H. V. 1943. *The production of malting barley.* J. Incorp. Brewers Guild, November 1943.

35. GARNER, H. V. 1943. *Straw composting.* Farmer & Stockbreeder, December 1943.

36. GARNER, H. V. 1941. *Agricultural salt.* Agriculture, **48,** 183-185.

37. NORMAN, A. G. 1939. *The composition of forage crops. III. Cocksfoot. Changes in the herbage during growth, with and without additions of nitrogenous fertiliser.* Biochem. J., **33,** 1201-1208.

38. CROWTHER, E. M. and WEIL, J. W. 1939. *Report on the analyses of barleys valued for the Rothamsted Conferences of* 1935, 1936 *and* 1937 J. Inst. Brewing, **45,** No. 12.

39. BUNTING, A. H. 1945. *Sewage sludge and the market gardener.* Agriculture, **52,** 123-126.

A general discussion of modern sewage sludges, their manurial value and use in composting straw.

40. CROWTHER, E. M. 1945. *Russians overcome late frosts in potatoes.* Farmer & Stockbreeder, July 17, 1129.

In an account of recent Russian developments in agricultural science, mention was made of methods of overcoming late frost damage to potatoes in the extreme north by planting in wide high ridges across the direction of the winds prevailing in the dangerous period of August and September.

41. CROWTHER, E. M. 1945. *Agrochemistry.* Nature, **156,** 227.

A review of some of the outstanding achievements of Russian agricultural chemistry, as demonstrated during the celebrations of the 220th Anniversary of the Academy of Sciences of U.S.S.R. in June, 1945.

42. CROWTHER, E. M. 1945. *Muck, magic and composts.* Farmer & Stockbreeder, **59,** 1960.

A review of Sir Albert Howard's "Farming and Gardening for Health and Disease."

43. CROWTHER, E. M. 1941. *5 cwt. of salt : 5 cwt. extra sugar.* Farmer & Stockbreeder, **55,** 620.

DEPARTMENT OF SOIL MICROBIOLOGY

By H. G. Thornton

Origin of the soil microbiology department

The present department was formed during the period under review by amalgamation of the earlier Bacteriology and General Microbiology Departments, shortly after the death of Mr. D. Ward Cutler, in January, 1941. The loss that his death entailed to Rothamsted and to soil microbiology in general is well appreciated by all who are acquainted with his work and particularly by those who had the honour to be his colleagues. Under his leadership the General Microbiology Department, started in 1919 for the particular study of soil protozoa, had extended its interests, as was inevitable, to cover other component groups of the soil micro-population, so that by 1941 no logical distinction in fields of work divided it from the Bacteriology Department and fusion of the two departments was a reasonable development.

This fusion was greatly facilitated by an important new environmental factor; in that year Bacteriology moved from its old home in the James Mason Laboratory into the new laboratories which had been built for it in the New Wing and which were designed to be continuous with those of the General Microbiology Department. These new laboratories, though completed in 1939, were not in fact occupied by the Bacteriology Department until 1941, because they were taken over until then by the Department of Public Health as an emergency war-time measure. Moreover the new combined department lost the use of four of its rooms. Two of them provided temporary quarters to Professor J. B. S. Haldane, F.R.S. and the Genetical Department of London University, welcome guests whose laboratories in University College had suffered bomb damage. One room similarly helped to house the Leather Research Association workers who were in the same plight. The fourth room was occupied by Dr. J. H. Quastel, F.R.S., Head of the A.R.C. Unit of Soil Metabolism. With the return of these rooms for the use of the Department a considerable increase in the number of workers has been possible.

Staff

The following Scientific Staff have worked in the Department or in the two Departments from which it arose, during the period under review, and are still working here unless otherwise stated.

Permanent Staff

D. Ward Cutler, M.A., formerly Head of the Department of General Microbiology, died January, 1941.

H. G. Thornton, B.A., D.Sc., F.R.S., formerly Head of the Bacteriology Department, now of the combined Soil Microbiology Department.

Lettice M. Crump, M.Sc.

Jane Meiklejohn, Ph.D. Joined the W.A.A.F. November, 1942. Demobilised, 1945.

P. S. Nutman, B.Sc., Ph.D., A.R.Sc.

Workers receiving grants from the Agricultural Research Council

Janina Kleczkowska, Eng.Agric., Ph.D., came in 1939.

Dagny Oxford, B.A., came in 1944.

B. N. Singh, M.Sc., Ph.D., came in 1938.

Janet Mollison, B.Sc., Ph.D., came in 1944.

P. C. T. Jones, B.Sc., A.R.Sc., came in 1944.

Workers receiving scholarships

H. K. Chen, B.Sc., Ph.D., came in 1937, left in 1940.

A. Vasco Garcia, Eng.Agric., B.Sc. (British Council Scholar), came in 1944.

S. Bhaduri, M.Sc. (Ghosh Scholar), came in 1944.

In addition to the above the Department is grateful for valuable help from a number of temporary and part-time workers, especially from Mrs. Kalmus and Mrs. Derry.

Scientific work

In the account which follows no attempt is made to separate the work of the combined Soil Microbiology Department from that of its two predecessors because the latter were already working on lines complementary to each other at the time of their amalgamation so that no radical change in programme was then found to be needed.

In the Soil Microbiology Department and its precursors, two main lines of research have been followed, first the study of the soil micropopulation as a whole and of the inter-relationships of its main constituent groups, and secondly investigations dealing with the nitrogen-fixing bacteria of leguminous plants. Other special investigations have been concerned with organisms that attack resinous substances incorporated in soil for making roads, with the occurrence of mycorrhizal associations in crop plants, with the assay of thiamin in potatoes, and with the toxicity to plants of 2 : 4-dichlorophenoxyacetic acid.

A. Soil micropopulation

In studying the soil micropopulation there is need for knowledge of the inter-relationships of the different groups and of the " micro-ecology " of the soil generally. Classical researches on soil bacteria have largely dealt with isolations studied in pure culture and too often assumptions have been made as to the production of chemical changes in the soil by organisms producing such changes *in vitro*, sometimes even without evidence that these organisms are active in soil. A proper understanding of biochemical changes in soil must, however, be based on further knowledge as to which organisms are in fact active in field soil and why they are able to maintain their active existence in the face of acute competition from other groups. For this reason the problem of competition between different

groups of the soil population has been constantly borne in mind in planning research.

The development of adequate methods for counting the individuals of different groups of the soil population is an obvious preliminary to the study of soil micro-ecology so that special attention has been paid to the development of new, and improvements in existing, technique.

1. *Direct microscopic examination of soil*

The fact has long been appreciated that the enumeration of bacteria, actinomycetes and fungi in soil when based on a plating technique necessarily gave counts that represented but a small fraction of the soil population. This is because no medium will support the growth of all the physiological groups of organisms differing so much in their food requirements. Moreover, in the case of fungi and actinomycetes the difficulty of knowing whether colonies arise from hyphae or from spores invalidates such counts as a measure of active mycelium in the soil. To meet this difficulty various methods have been evolved for the direct microscopic examination of stained films of soil and for the counting of bacterial cells in them. These methods have usually involved the staining of films of soil suspension dried on a slide or cover-slip and stained with one of the eosin dyes. The only method that had given satisfactory results on statistical tests when applied to the enumeration of bacterial cells in soil was the ratio method of H. G. Thornton and P. H. H. Gray (1934, Proc. Roy. Soc. Ser. B., Vol. 115, p. 522). This is based on an estimate of the relative numbers of bacterial cells and indigo particles, a known number of the latter having been mixed with a suspension of the soil sample. The erythrosine dyes, however, give a weak stain to many organisms in soil and are unsuited to staining fungal and actinomycete mycelium, while drying of the film makes it difficult to observe all the bacterial cells embedded in small soil aggregates. A new quantitative method has now been evolved by Miss J. Mollison and Mr. P. C. T. Jones in which films of a suspension of the soil in agar are mounted and examined in euparal. The method at present used is as follows. A known quantity of soil is shaken with a known volume of melted 1.5 per cent. agar. A drop of the mixture is allowed to solidify on a haemocytometer slide of 0.1 mm. depth to produce a film of known thickness. The resulting film is transferred to a microscope slide, stained in acetic aniline blue and examined in euparal. Counts of micro-organisms are made in 20 random microscope fields on each of 4 replicate slides. The volume of the 20 fields is readily calculated and from this the number of bacteria per gram of soil can be obtained. In a test of the method, bacterial counts from duplicate samples of soil each examined independently by two workers gave a mean count of 3,334,000,000 bacterial cells per gram with a standard error of 5·9 per cent. When a previously counted suspension of bacteria was mixed with sterilised soil the numbers " recovered " were 93 per cent. of those added.

The method can also be used to estimate fungal and actinomycete

mycelium, which stains excellently by it. Here the fragments of hyphae are counted and measured. In a test comparison of replicate soil samples, a mean length of 393 metres of mycelium was found per gram of soil, this estimate having a standard error of 10.45 per cent. Both the above estimates were made from Rothamsted allotment soil. That for bacteria is of the same order as those previously obtained from the soil by the ratio method with added indigo particles. No previous estimates of fungus mycelium in soil by direct measurement have been made. The estimated length of 393 metres represents a total volume of 0.69 mm.^{3} assuming the mycelial hyphae to have a mean diameter of 1.5μ. This compares with the 3.3 mm.^{3} per gram represented by the 3.3×10^9 bacteria found in the same soil.

2. *Plating technique*

Although estimates of total numbers of bacteria and quantity of mycelium in soil can be obtained only by direct examination, such methods do not enable the organisms to be isolated and studied. Nor can any division into physiological groups be obtained by them. For this reason the complementary information yielded by plating and dilution methods is still needed. A fresh study has therefore been made by Mr. A. Vasco Garcia of the statistical errors inherent first in taking samples from the field and secondly in the various stages of the plating technique.

3. *Survey of the micro-population of differently manured plots*

This survey has been undertaken with the object of determining what differences occur in the soil micro-population in plots given farmyard manure and artificials. Bacterial colony counts on two plating media, and estimates, based on dilutions, of cellulose-attacking organisms and of amoebae have so far been made from plots of Barnfield (mangolds) that received (*a*) no manure or fertiliser, (*b*) farmyard manure and (*c*) complete minerals and ammonium sulphate. The results indicate that whereas farmyard manure has considerably raised the level of the soil micro-population owing doubtless to its supply of energy material, the treatment with artificials has also increased numbers of both bacteria and amoebae relatively to the no-manure plot. This confirms data previously obtained by direct counts of bacterial cells, in showing that such artificial manuring, after many years of application, has increased rather than decreased the population level of the soil micro-organisms.

An attempt is being made to divide the bacteria found on platings from these plots, into physiological groups, using a modification of the methods developed in Canada by Lochhead.

4. *Characterisation of common soil bacteria*

A survey has been made by Miss L. M. Crump of the commonly occurring bacteria that appear on dilution platings of soil. Fifty-three soil samples comprising both arable and pasture were examined. Sixteen strains of bacteria were found to occur in at least ten of these samples, seven of them occurring in at least twenty samples. Different strains tended to be predominant in arable and grassland

respectively, although a few strains were common in both situations. The soil reaction also affected the abundance of certain strains. The cultural characters of these sixteen common strains have been compared with those of a number of relatively rare strains obtained from the same soils. But the abundant could not be separated from the "rare" types by any common feature in their morphology or in their physiological behaviour.

The problem of why these particular bacteria predominate in soil in the field raises the important question of competition between groups of the micro-population. Dr. B. N. Singh has determined the multiplication rates in soil of a number of common and rare soil bacteria. There is a tendency for the former to have higher rates of increase in sterilised soil, but there are exceptions to this rule. Other factors must also be looked for and competition or inhibition by other organisms is obviously suggested. This problem is being studied with regard to several groups of organisms.

5. *Differential feeding of soil protozoa*

It was known from the work of Cutler, Crump and their colleagues that the numbers of bacteria in soil are kept down by protozoa and that their numbers fluctuate inversely to those of soil amoebae. (D. Ward Cutler, L. M. Crump and H. Sandon, 1922. Phil. Trans. Roy. Soc. London, Ser. B., Vol. 211, pages 317-350). Dr. B. N. Singh has found that amoebae and holozoic flagellates obtained from soil are very differential in their bacterial food requirements (15, 16, 17). Some bacterial strains are readily edible by all soil protozoa tested, others are inedible to some or all of these protozoa, which will die if supplied with a pure culture of such bacteria. Bacteria producing pigments other than yellow or orange were nearly all found to be inedible to amoebae (19). Some bacteria are not only inedible but produce secretions that are highly toxic to amoebae (18, 19). The existence of bacterial strains edible, inedible and toxic to protozoa clearly means that the latter can affect both the total numbers and also the quality of the soil bacterial population by differential feeding.

6. *Estimation of protozoal numbers in soil*

This discovery of edible and inedible bacteria has enabled Dr. B. N. Singh to develop a much more reliable method for estimating numbers of protozoa in soil than the method previously used, which consisted in applying a range of soil dilutions to poured plates of "nutrient" (peptone-meat extract) agar and counting the number of plates that produced a growth of protozoa. The bacterial food was derived from such bacteria as developed from the soil suspension. An evident source of error lay in the possibility that a protozoan added to a plate might come to lie amongst bacteria inedible or toxic to it. In the present technique, plates of plain agar are poured and a pure culture of an edible bacterial strain is spread on the plate surface in the form of patches each surrounded by a glass ring. These patches are then inoculated from the soil dilutions. Eight such patches can be fitted into one petri dish thus giving a good replication with an economy of plates. By this method a protozoan if present in the inoculum is assured of a suitable bacterial

food and will not be exposed to toxic bacterial secretions. The number of protozoa is estimated by the number of patches in which they develop at each dilution. A statistical examination has been made of the results of this method with satisfactory results.

7. *Occurrence of giant rhizopods in soil*

Certain giant multinucleate rhizopods have from time to time been observed in soil by previous workers, but were believed to be rare and of little importance in the soil economy. The use by Dr. B. N. Singh of edible bacteria for cultivating and counting soil protozoa has now realed the occurrence of such a rhizopod in the soil of our classical plots in numbers of the order of 1,000 per gram. Since this organism can attain a volume some 250,000 times that of a soil amoebae it seems likely to be of some importance in affecting the bacterial population of the soil.

8. *Distribution and behaviour of Acrasieae in soil*

This very interesting group of organisms was known to occur in soil, but was previously believed to be adventitious and derived from manure: nothing was known of its distribution. Dr. B. N. Singh's method of culture has enabled him to study the distribution of Acrasieae and roughly to estimate their numbers in soil. They occur in nearly all arable soils examined both from our own plots and elsewhere, but are much less abundant in grassland soils. Their occurrence in plots treated over a long period with artificials only shows that they are normal soil inhabitants and not dung organisms. They can pass through all the stages of their life-cycle in sterilised soil inoculated with edible bacteria, and cause a marked reduction in the numbers of the latter. Both Acrasieae and giant rhizopods are differential in bacterial food requirements, but differ in some cases from amoebae in the types of bacteria that are edible to them. The type of bacterial food so greatly affects both the shape and the colour of the sporangium produced by Acrasieae as to invalidate the present classification of these organisms, which is based on these characters.

Myxomycetes have also been found to be easily obtained from soil by Dr. B. N. Singh's method.

9. *Soil myxobacteria*

The great interest of this group of organisms owing to their morphology and life-cycle has lately aroused the active interest of a number of workers in different countries. Dr. B. N. Singh has found that certain species are readily cultivated from soil by his method and can be found in many soils. As with the Acrasieae their occurrence in plots treated only with artificials disproves the common opinion that they are derived from dung. They occur in soil in numbers of the order of 70,000 per gram. The species studied produce extremely active proteolytic and bacteriolytic enzymes which can lyse many species both of gram-positive and gram-negative Eubacteria. When grown on agar media, the myxobacteria can readily attack living bacteria including gram-negative types.

10. *Soil actinomycetes*

The actinomycetes form a numerically important section of the soil's micro-population, but technical difficulties have so far prevented us from knowing much about their numbers, habit of life or physiological activities in the soil. On agar media they show striking differences in habit of growth and pigment formation, but in the soil itself their growth is quite different and uncharacteristic. Dr. Dagny Oxford, in a study of their habit of growth in soil and sand culture, finds that this depends chiefly on physical properties such as particle or crumb size and moisture content. In the substance of the soil they occur as straggling mycelia with occasional sporing branches, while on the soil surface tufts of aerial mycelium are formed, which are quite different in appearance from their colonies on an agar surface. Under dry conditions in soil there is an enhanced development of aerial mycelium and spores, both of which possess a waxy coat which doubtless assists survival. This waxy coat makes a dispersed suspension of spores difficult to obtain and thus affects the counting of actinomycetes by the plate method.

Dr. Oxford has also studied the nutrient requirements of actinomycetes in a synthetic " soil " composed of sand and bentonite, and found that they need only very dilute solutions of nutrient salts and can obtain nitrogen from a highly resistent organic source. Many of the soil actinomycetes secrete bacteriolytic substances. Most of these act only on gram-positive bacteria. The nature of this specificity is being investigated.

11. *Mycorrhizal associations in crop plants*

It has been claimed that common agricultural crops benefit from mycorrhizal associations. There is, however, very little known as to the frequency of occurrence or functions of mycorrhizae in agricultural crop plants. Dr. Janet Mollison has made a search for them in clover and in wheat. She found a phycomycete fungus forming such associations in nearly all clover plants examined which were obtained from widely scattered localities in Great Britain. Similar mycorrhizae have also been found in wheat roots although in this case their occurrence seems to be more seasonal.

B. The nodule bacteria (*Rhizobium*) of leguminous plants

The work on this subject has dealt mainly with the differences between strains of nodule bacteria, particularly those infecting clover, and with the problems arising therefrom. It was known that strains of these bacteria derived from a single host species differ greatly in the benefit that they confer on the host plant. Some strains produce nodules that fix very small amounts of nitrogen and confer no visible benefit on the host when grown in a nitrogen-deficient medium. These *ineffective* strains are particularly prevalent amongst clover nodule bacteria, and our preliminary survey suggested that such ineffective strains were to be found especially in poor hill pastures. An investigation was therefore commenced with the ultimate object of improving the clover content of such pastures, either by inoculation with beneficial (i.e. effective) strains of bacteria, or by so changing the soil conditions as to encourage more beneficial strains to develop.

1. *Distribution of strains of clover nodule bacteria in Great Britain*

The first need was a knowledge of the geographical distribution of ineffective strains of clover *Rhizobium*, in order to know in what districts inoculation might help and also what soil conditions encourage the development of beneficial and ineffective strains, respectively. A survey of the distribution of strains of clover *Rhizobium* over Great Britain has therefore been undertaken. Clover plants have been collected from districts covering most of Great Britain, and from the nodules on these plants isolations of the bacteria were made. Each strain isolated has been tested for effectiveness in fixing nitrogen on clover grown aseptically in nitrogen-deficient agar medium. So far 463 strains have been isolated and tested and 126 others are under test. From 290 isolations obtained from Scotland, Wales and from the North and West of England, 28 per cent. were ineffective, 12 per cent. were intermediate in effectiveness and 60 per cent. were effective. From the South, Centre and East of England 173 strains have been tested; of these 9.2 per cent. were ineffective, 4.6 per cent. intermediate and 86.2 per cent. effective. The ineffective strains were mostly obtained from hill pastures, but so far it has been impossible to correlate their occurrence with any particular soil type.

2. *Serological characters of nodule bacteria*

During the course of the geographical survey described above a study was made of the serological behaviour of the strains isolated. The object of this investigation was to develop an additional means of classifying and identifying the strains, and also to see whether the effectiveness of a *Rhizobium* strain in fixing nitrogen was correlated with any serological character that might then be used as a quick means of selecting effective strains. In collaboration with Dr. A. Kleczkowski (8), 161 strains of *Rhizobium* from clover and 29 strains from plants of the pea group were tested for agglutination with antisera against four strains of clover *Rhizobium* and two strains from pea.

The bacterial strains tested were found not to contain any antigen common to the whole group. Some strains reacted with none of the antisera, some with several of them, but none with all of them.

Strains entirely unrelated in antigenic structure could be found amongst those isolated either from clover or pea. On the other hand some strains from peas showed close resemblance in antigenic reactions to some derived from clover. Classification by antigenic structure thus fails to support the separation of the clover and pea nodule bacteria into different species. Nor was any necessary association found between the antigenic structure and effectiveness in fixing nitrogen or susceptibility to bacteriophage. Indeed an effective strain and a very ineffective variant from it were found to be serologically identical. The knowledge gained of the serological behaviour of clover and pea nodule bacteria has since been of much use in identifying strains introduced into a field soil and picked out again, as will be described later.

The serological relationship between clover and pea *Rhizobium* suggested that strains might be found that would infect both host

plants. Tests of a number of strains were therefore made by Dr. P. S. Nutman and Dr. J. Kleczkowska at Rothamsted and by Dr. Bond at Glasgow (7). These tests revealed several strains capable of infecting both host plants, although in no case were the strains effective on the " wrong " host.

3. *Competition between strains*

Before there is much hope of improving the growth of clover by the inoculation of soils infected with ineffective strains, there are at least two difficulties that must be surmounted—namely (*a*) competition of the " wild " bacterial flora with the strain used to inoculate the soil and (*b*) lack of stability of effective strains in certain soils. These difficulties will be separately considered.

When a pea or clover plant is supplied with a mixture in equal numbers of two strains of *Rhizobium* both capable of infecting it, some 80 to 95 per cent. of the resulting nodules are usually produced by one of the two strains. In an investigation of this phenomenon Dr. H. Nicol and Dr. H. G. Thornton (12) showed that it resulted from a corresponding competition between the two strains in the surroundings *outside* the plant roots. No evidence of a differential resistance to infection by the plant roots could be found, but the presence of these roots stimulated the bacteria to multiply in their neighbourhood, whereupon the strain having the higher initial multiplication rate suppressed growth of the other strain. Similar competition between bacterial strains could be induced in the absence of roots by the addition of a source of energy.

This competition appears to be specially acute between strains capable of infecting the same host plant. It has an important bearing on the use of inoculation in the case of soils bearing ineffective strains. In the past, practical success with legume inoculation has most usually been obtained in cases where it was used to supply a legume crop with nodule bacteria capable of infecting it, in a soil from which these were absent often because the crop was of relatively recent introduction. Here, of course, there is no problem of competition with other strains capable of infecting the crop. The case is very different where we seek to replace a wild population of ineffective strains by a relatively small inoculum of a beneficial but otherwise very similar strain that will at once be subjected to inter-strain competition in the soil.

Fortunately when choosing strains for such inoculation under field conditions use can be made of the fact that strains differ specifically in their ability to compete with others in the soil. A strain found to be thus successful in laboratory tests has proved similarly able to maintain itself in the field. The study of the competition between two pure strains placed under laboratory conditions is relatively easy. But when a strain is used to inoculate seed, the competition to which it is exposed in the field soil is much more difficult to investigate. The main difficulty is that of identifying the individual strain inserted into the soil in the midst of a large and unknown number of wild strains most of which will be indistinguishable from it in culture. The extensive survey of serological reactions of clover bacteria outlined above has now given us a means of identification. For it is now possible to select, for

seed inoculation, strains belonging to uncommon antigen groups and against which an antiserum has been prepared. After the clover has grown, isolations can be made from random nodules taken from inoculated and uninoculated plots and those isolations which are of the same strain as the seed inoculum can be identified by agglutination with the appropriate antiserum. In this way one can determine what percentage of the nodules in a field plot sown with inoculated seed has in fact been produced by the strain used to inoculate that seed. Experiments of this nature have been carried out at four centres in widely scattered districts with different soil types. Two strains of clover nodule bacteria were tested, both equally effective in pure culture. One of them produced an average of 59.1 per cent. of the nodules in plots sown with seed inoculated with it, the other strain produced an average of only 12.9 per cent. of the nodules, in competition with the wild strains.

Such results have an important bearing on the issue of cultures for seed inoculation for they show that, in choosing strains for this purpose, effectiveness in fixing nitrogen under laboratory or glasshouse conditions in pure culture is not an adequate criterion ; a suitable strain must also be able to survive competition with other strains in the field soil. The exact characters that give a strain this competitive superiority need investigation, but we have found that initial multiplication rate in sterile soil supplies a rough measure of a strain's competitive strength.

4. *Changes in effectiveness in pure strains*

The second difficulty confronting our attempts to improve clover by inoculation is the instability of *Rhizobium* strains in some soils. It has long been known that bacterial strains often show a marked tendency to change their characters. Our present knowledge of bacterial genetics is still primitive and such changes have the appearance of being of two kinds—slow adaptive changes and sudden changes resembling mutations. Changes in effectiveness of strains of *Rhizobium* had been observed before, and it was claimed that a slow adaptive change in effectiveness could be brought about by repeated passage of a strain through the host plant. If this were proved to be so it would have an important bearing on crop rotation. A very extensive test was made by Dr. P. S. Nutman in which an effective strain A was passed thirteen times through the clover plant, and during these passages attempts were made to change the strain by selection and isolation from large and small nodules and from plants deriving more or less benefit from the bacteria. Neither frequent plant passage nor deliberate selection had the smallest effect on the bacterial strain or on its action on the plant whether judged by its effectiveness in benefiting the plant or by the mean size of nodule—a character well correlated with effectiveness.

A similar series of plant passages likewise failed to produce any change in an ineffective strain.

The strains of *Rhizobium* used in the above extensive series of experiments were thus very thoroughly tested for purity and constancy of behaviour. Nevertheless when the effective strain A was afterwards stored for nine months in sterilised Woburn soil,

platings made from these soil cultures produced colonies, 35 per cent. of which consisted of a highly ineffective mutant strain which retained its new character in culture for several years. Dr. J. Kleczkowska has been investigating such mutations in soil culture and finds that they occur readily in some soils, but not in others. At present we do not know what character in the soil determines whether mutants of the nodule bacteria will appear in it. Addition of NPK or changes in reaction do not alter the soil's natural tendency in this respect. The problem is one of great importance to the practice of legume-seed inoculation since it is clearly of little use to add effective nodule bacteria to a soil in which they will turn into ineffective strains.

Similar mutant forms have also appeared in old agar-slope cultures and when cultures have been stored at a low temperature. Until recently all such variations in effectiveness have been less effective than the parent strain, and by no means could the effectiveness of a strain be increased, although when passing the ineffective mutant S_2Q, obtained from soil, through the plant a very small percentage of effective mutants appeared. During the past year, however, Dr. Kleczkowska in her work with bacteriophage (see below) has obtained an interesting series of mutant types amongst the 'phage-resistant survivors left after treating the ineffective mutant strain S_2Q with bacteriophage. These mutants not only include remarkable rough and pigmented forms, but also a proportion that have regained their effectiveness towards the host plant characteristic of the original strain A from which the ineffective mutant S_2Q was obtained by storage in soil. These variants from strain A, some ineffective, some that have regained a lost effectiveness and others with aberrant types of growth on media, all resemble the parent strain in their serological reactions.

5. *The cause of ineffectiveness*

When the existence of ineffective strains of *Rhizobium* was first discovered, it was generally believed that these strains lacked the ability to utilise nitrogen gas owing to some defect in their enzymic constitution. This could not be demonstrated owing to the difficulty of getting any strain, whether effective in the plant or not, to fix nitrogen *in vitro*. It had, however, been noticed that ineffective nodules tended to remain small, and it thus seemed possible that their ineffectiveness might be related to the anatomy or physiology of the nodule as a whole. The anatomy and development of nodules produced by effective and ineffective strains were therefore investigated by Dr. H. K. Chen and Dr. H. G. Thornton (2). This investigation included nodules developed on clover, peas and soybeans.

The main differences between effective and ineffective nodules were found to concern the central tissue whose cells contain the bacteria and which is here called the " bacterial tissue."

The conclusions may be summarised as follows.

First. In effective nodules the bacterial tissue attains a much greater volume than in ineffective nodules. In soybean nodules, there is, in additions, a much larger percentage of infected host-plant cells within this tissue in effective than in ineffective nodules.

Secondly. In effective nodules the bacterial tissue has a much longer active life. In all nodules, by whatever strain they are produced, the bacterial tissue finally disintegrates. This is due to the bacteria becoming actively parasitic and destroying the nodule tissue. The details of this remarkable phenomenon have been elucidated by earlier Rothamsted work (W. E. Brenchley and H. G. Thornton, 1925. Proc. Roy. Soc. Ser. B. Vol. 39, p. 373 : H. G. Thornton, 1929. Proc. Roy. Soc. Ser. B. Vol. 106, p. 110). In effective nodules this disintegration of the bacterial tissue begins when the nodule is three to four months old and is complete in a further one or two months. The tissue thus has an active life of perhaps four months. In ineffective nodules the small volume of bacterial tissue is completely disintegrated when the nodule is two weeks old. Effective nodules thus differ from ineffective ones both in the volume and in the duration of the active bacterial tissue. The total volume (v) of bacterial tissue in a nodulated plant can be estimated, as well as its mean duration (t) before it disintegrates. If we determine the increase in nitrogen content (n) of such a plant grown in a medium lacking combined nitrogen, it is possible to estimate the quantity of nitrogen fixed by a unit volume of bacterial tissue in a unit time $\left(\frac{v\ t}{n} = f\right)$. It was found that this quantity (f) was the same for an effective as for an ineffective strain, hence, amongst the strains studied, the ineffectiveness was due not to an inability to fix nitrogen, but to the bacteria of the ineffective strain being unable to multiply sufficiently or to last for long enough within the plant's tissues. Some evidence has been produced that this inability is related to the production in ineffective nodules of some substance in the root juice that is toxic to the nodule bacteria (3). There is another noticeable difference in fresh material that distinguishes effective from ineffective nodules. The remarkable haemaglobin pigment is as a rule easily seen in effective but not in ineffective nodules. This fact has been recently stressed by Virtanen : it seems explicable by the very short duration of the bacterial tissue in ineffective nodules, which could scarcely give time for visible amounts of pigment to accumulate.

6. *Variation in the response of the host plant to infection*

We have so far considered the changes in effectiveness due to variations in the nodule bacteria. But since the cause of ineffectiveness lies in a failure of the correct adaptive balance between the host plant and the bacterium, we should expect the plant also to exhibit variation affecting this balance. Indeed, during the extensive tests of bacterial strains on clover and especially during Dr. Nutman's investigation of strain stability on plant passage, the very large number of replicates examined and analysed brought out the fact that a considerable variance both in nodule size and effectiveness was attributable to variation in the host plant. Further tests showed that when seedlings from a commercial sample of red clover were supplied in replicate with a normally effective bacterial culture, one or two per cent. of them showed an ineffective response. On the other hand when a bacterial strain of low effec-

tiveness was used a few of the replicate plants showed a response much above the average. With the highly ineffective strains tested, however, uniformly ineffective responses have been obtained. This variance in effectiveness attributable to the clover plant has been shown to be hereditary by Dr. P. S. Nutman (*Nature*, Vol. 147, p. 463) who has carried out a genetical analysis of some of the factors concerned. Recessive genes in red clover produce ineffective responses when their homozygotes are infected with the normally effective bacterial strain A. These genes are highly specific in their action towards certain bacterial strains, for the same recessive gene in the host plant will produce an ineffective response with the parent bacterial strain A, but will allow other unrelated strains and even a bacterial mutant derived from strain A to produce an effective response.

7. *Factors controlling infection and nodule numbers*

The work on *Rhizobium* already outlined was either concerned with or arose directly from the study of differences in the effectiveness with which nodules fix nitrogen. But not only is the effectiveness of nodules, when formed, determined by the joint action of factors in the bacterial strain and of genes in the host plant, but a similar joint control also determines whether the root shall be infected and the number of nodules that are produced.

On the bacterial side, in a number of cases, strains of *Rhizobium*, some effective and some ineffective, have lost their power of producing nodules on the host plant. Drs. H. K. Chen and P. S. Nutman studied some of these avirulent variants and found that they were unable to infect the root hairs, but were able to produce that characteristic deformation or curling of the root hairs which is the preliminary stage of infection. The study of the bacterial secretions producing this curling and the investigation arising from this is described in a later section.

The number of nodules produced by a given bacterial strain is subject to an upper limit. This limit is, of course, affected by the plant's physiology as will be seen, but also by some factor in the bacteria, since Dr. H. K. Chen (1) has found that the number of nodules per gram of root is a characteristic of the bacterial strain used.

On the plant side a case of the complete inhibition of nodule formation due to genes in the clover host plant has been investigated by Dr. P. S. Nutman. A plant completely resistant to infection appeared amongst some clover seedlings supplied with nodule bacteria. This was grown to maturity, and a genetical analysis made of its offspring. Resistance to infection here depends on a recessive gene which can, however, cause the resistance only if homozygous in a female plant of a particular genetic constitution. This very interesting type of inheritance, of course, results in such resistant plants being very rare in nature. Other genes in the clover plant have also been found by Dr. P. S. Nutman to influence the time at which the first nodule appears and the number of nodules produced by a given strain of bacteria. The time of first appearance of nodules is typically coincident with the opening of the first leaf as found by Dr. H. G. Thornton in lucerne, but genetical factors

in the plant can delay their appearance considerably. Both the first appearance and number of nodules are controlled by factors in the plant that produce a blending type of inheritance suggestive of a complex genetical picture not yet analysed.

The relation between the rooting habit of the clover plant and the number of nodules formed has been studied by Dr. P. S. Nutman, using lines of clover plants selected to form differing numbers of nodules at maturity. In this material the mean number of nodules produced by the effective strain A was found to be correlated with the rate of lateral-root formation, but not with the total length of the root system. Moreover, inoculated seedlings developed fewer lateral roots than uninoculated, the nodules seeming to replace lateral roots. These results suggest that there are points in the roots capable of developing laterals or, if infected, of producing nodules, and that the number of such points is influenced by genetic factors in the plant. Further work is needed to investigate these relationships using different bacterial strains, since, as mentioned above, these also differ characteristically in their potentiality in producing few or many nodules.

Dr. P. S. Nutman has also found that in agar cultures the number of nodules and of laterals developed on clover was determined by the number of plants sharing the same root space (13). This reduction cannot wholly be accounted for by competition for nutrients. Addition of nutrient solution in which other clover plants have grown decreases nodule numbers while the addition of distilled water increases them. Moreover, if lucerne and clover seedlings are grown in the same tube, lucerne reduces the number of nodules on clover to the same degree whether or not the lucerne is also inoculated, but clover reduces the number of nodules on lucerne only if the clover is also inoculated. The further investigation of such interactions may throw light on the competitive root action between mixed crops.

8. *Bacteriophage*

The investigation of *Rhizobium* bacteriophage was begun because claims have been made that the failure of legume crops, particularly lucerne, may be due to the decay of nodules caused by bacteriophage. Moreover, the presence of 'phage in soil might well affect the competition between strains of *Rhizobium* the importance of which has been illustrated above. The investigation has been carried out by Dr. Janina Kleczkowska using a 'phage originally isolated from garden soil surrounding the roots of peas, and originally grown on pea *Rhizobium*. Quantitative studies were greatly facilitated by an improvement in the technique for producing " plaques," by using poured platings in which the diluted 'phage suspension was mixed with a young culture of the host bacterium in melted agar before pouring the plate (5). Statistical examination of this method showed that by it valid comparisons could be made between the numbers of particles in two or more 'phage suspensions.

The plaques produced by this method develop in the substance of the agar by lysis of the numerous microscopic bacterial colonies, thus enabling the action of 'phage on bacterial colonies of different ages to be studied. By use of this technique the successive

phenomena that occur during 'phage attack on a bacterial culture were followed quantitatively (6). The secondary development of bacterial growth in a culture apparently cleared by 'phage was also investigated. It was found that this growth often consisted of susceptible bacterial cells co-existing with a high concentration of potentially active 'phage, but protected against its action by some product of the previous lysis of bacteria.

The 'phage used in this investigation attacked a small number only of the bacterial strains upon which it was tested, but these include clover as well as pea *Rhizobium*. It has been possible to separate from the original crude 'phage a number of 'phage strains more specific in their action and also differing from the original 'phage in the mean size of the plaques produced by them.

A number of interesting 'phage-resistant mutants of clover *Rhizobium* have been isolated from cultures after subjection to 'phage. Some of these, as mentioned above, differ in effectiveness towards the host plant. Others are very abnormal in growth characters, being " rough " or pigmented on agar. The addition of 'phage to a culture of *Rhizobium* in sterilised soil rapidly converts this into a 'phage-resistant population. This fact and the specificity of 'phage strains makes it improbable that wholesale destruction of nodules in a crop can be brought about by 'phage. Moreover, attempts to induce 'phage to enter and attack growing nodules were unsuccessful. But 'phage is a very useful laboratory tool, as the specific strains can be used to identify susceptible strains of *Rhizobium* isolated from a mixture, and 'phage provides a rapid method of obtaining interesting and perhaps useful mutant forms of the bacteria.

C. Special lines of work

1. *The use of the fungus* Phycomyces Blakesleeanus *in the estimation of thiamin in potatoes*

The Phycomyces method for assaying thiamin was found to be valid for this use in potato tubers and was applied to study the increase in thiamin content during growth of the tubers and the loss that occurs during storage in winter and spring. This loss was especially great during spring storage, when it was apparently related to sprouting (10). Experiments showed that after heating in a steamer for 45 minutes on three successive days the thiamin was not destroyed, but that the bulk of it was washed out into the liquid in which the pieces of potato were immersed (9).

2. *The relation of organisms to decay of resins added to soil*

This piece of research has been undertaken at the request of the Road Research Board (D.S.I.R.) and concerns a problem involved in processes for making temporary roads by incorporating various resinous powders in the soil in order to waterproof the road base. Failure of such roads occurs in circumstances suggestive of attack by micro-organisms, but nothing was known about soil organisms that could attack such substances. In preliminary tests, however, Miss L. M. Crump isolated a variety of soil bacteria that could attack the resins and use them as a source of energy.

Mr. P. C. T. Jones is investigating the matter. He has isolated

a number of resin-attacking organisms, both bacteria and fungi, and has shown that their presence decreases the waterproofing action of the incorporated resin in experimental blocks made up with it, and has obtained evidence of the increase in numbers of such organisms in an actual road made with resins, that was beginning to fail. The incorporation of antiseptics in the soil with the resin is being tested, so far with encouraging results.

3. *The discovery of the use of dichlorophenoxy-acetic acid in controlling plant growth*

This work began as a result of the previous study by Dr. H. K. Chen of the deformation of legume root hairs by secretions of *Rhizobium*. This suggested that the active substance in the secretions was β-indolyl-acetic acid, since the addition of tryptophane, the precursor of β-indolyl-acetic acid, to media caused an enhanced production by the bacteria of plant-growth substance. The action of β-indolyl-acetic acid itself was therefore tested on clover seedlings under aseptic conditions, and it was shown that the pure compound would, in fact, produce root-hair deformation similar to that produced by bacterial secretions. In these experiments it was also noticed that both this compound and the related plant-growth substance α-naphthyl-acetic acid were exceedingly toxic to clover seedlings grown aseptically in agar, toxicity showing at a concentration of 1 to 0.1 part per million of the solution. The two compounds were tested in fresh soil, but were found to be without toxic effect, no doubt owing to their rapid destruction by soil micro-organisms. A search was threfore made for some molecule known to be physiologically active towards plant growth that would be less likely to be attacked by micro-organisms. A chlorinated molecule seemed likely to meet this requirement since such organic molecules are usually resistant to bacterial attack. A likely compound answering these requirements was 2:4—dichlorophenoxy-acetic acid. This and several other compounds were therefore tested and the former was found to have a toxicity towards clover seedlings grown aseptically that was as high as β-indolyl-acetic acid, and to maintain a high toxicity even in unsterilised soil. Further tests on other plants showed that 2 : 4 — dichlorophenoxy-acetic acid was differentially toxic. Its toxicity was very high towards sugar beet and clover, but ten or a hundred times the concentration was needed to damage wheat. This investigation was carried out conjointly by Dr. H. G. Thornton, Dr. P. S. Nutman and Dr. J. H. Quastel (Head of the A.R.C. Unit of Soil Metabolism) (14). At this point the results were reported to the A.R.C. and further work was carried out in collaboration with Imperial Chemical Industries mostly at Jealott's Hill. In this work a large number of compounds were tested on a wide variety of plants, and field trials were carried out. 2 : 4 —dichlorophenoxy-acetic acid and a related methylated derivative, found in the above tests to be similarly effective, were also included in an extensive series of weed-control experiments carried out by Dr. G. E. Blackman of Imperial College. As a result of these further investigations, both compounds are now being successfully used in practice for the differential control of weeds in cereal crops.

PUBLICATIONS

1. Chen, H. K. 1941. *The limited numbers of nodules produced on legumes by different strains of* Rhizobium. J. Agric. Sci., **31**, 479-487.

Pot experiments were made with red clover and with soy beans to determine how far the number of nodules developed was a specific character of the strain of *Rhizobium* supplied.

The number of nodules per gram of root was found to reach a limit specific to each strain. This limiting equilibrium was attained regardless of the size of the root system or the age of plant at which the culture was first supplied, provided enough time were allowed for the limit to be reached.

When two different strains were applied to the root surroundings in succession, the final number of nodules was determined by the limit specific to the strain in contact with the roots while these were making most of their growth. In clover this was the second and in soy beans the first applied strain.

2. Chen, H. K. and Thornton, H. G. 1940. *The structure of " ineffective " nodules and its influence on nitrogen fixation.* Proc. Roy. Soc. B., **129**, 208-229.

In clover the mean volume of active bacterial tissue is about three times as great in " effective " as in " ineffective " nodules owing to an early arrest of growth in those produced by ineffective strains. In all nodules the active bacterial tissue eventually disintegrates, but in effective clover nodules it remains without disintegration for about six times as long as in effective nodules.

In clover inoculated with an effective and an ineffective strain the difference in the amounts of nitrogen fixed could be accounted for by the differences in volume and in duration of the active bacterial tissue.

In peas, nodules produced by an effective strain were nearly twice the length of those produced by an ineffective strain, and their bacterial tissue remained without disintegration for about twice as long. In soy beans the mean volume of bacterial tissue was 4·75 times as great in effective as in ineffective nodules and the percentage of that volume composed of infected cells was twice as great. In effective soy-bean nodules disintegration of the bacterial tissue began when the plant was 4 weeks old and was practically complete by the 12th week, at which time no disintegration could be found in effective nodules.

The difference in amount of nitrogen fixed by soy bean plants bearing each type of nodule could be accounted for wholly by the factors mentioned above. Thus in both clover and soy bean nodules the volume and duration of the active infected tissue are the main, if not the only, factors determining differences in nitrogen fixation amongst the strains tested.

3. Chen, H. K., Nicol, H. and Thornton, H. G. 1940. *The growth of nodule bacteria in the expressed juices from legume roots bearing effective and ineffective nodules.* Proc. Roy. Soc. B., **129**, 475-491.

Strains of pea and soy-bean nodule bacteria, differing in their effectiveness in benefiting the host legume, were grown in media containing the unheated root juices from uninoculated host plants and from host plants bearing effective and " ineffective " nodules, and their growth was measured.

The growth of the different bacterial strains on root juice from uninoculated plants was not correlated with their effectiveness.

The juice from roots with effective nodules produced significantly better growth of the bacteria than juice from roots with ineffective nodules in twenty-seven comparisons out of forty-four, the differences in the remaining comparisons being insignificant.

The juice from roots with effective nodules produced significantly better growth than the juice from uninoculated roots in ten comparisons out of twenty-five, and significantly poorer growth in three comparisons.

The juice from roots with ineffective nodules produced significantly poorer growth than the juice from uninoculated plants in eleven comparisons out of twenty-five, and better growth in only one comparison.

The production, as a result of infection, of soluble substances affecting growth of the bacteria, affords an explanation of those differences in nodule growth that determine the effectiveness or ineffectiveness of the different strains of bacteria as regards nitrogen fixation within the host.

4. Dixon, A. 1939. *The Protozoa of some East Greenland soils.* J. Anim Ecol., **8**, 162-67.

The protozoan species occurring in twelve soils from East Green land were determined, a large protozoan population was present in soils frozen for nine months in the year, and there was an unusually large number of species of testaceous Rhizopods. The largest numbers of species occurred in the soils supporting the richest vegetation.

5. Kleczkowska, J. 1945. *The production of plaques by* Rhizobium *bacteriophage in poured plates and its value as a counting method.* J. Bact., **50**, 71-79.

A statistical examination of plaque counts, using a technique of poured plates, showed that this method can be so standardised as to give reliable estimates by which 'phage suspensions can be compared. The 'phage studied was derived from garden soil surrounding the roots of peas and first grown on pea nodule bacteria.

Plaques produced by this method developed in the substance of the agar by the lysis of the minute bacterial colonies developing therein. These colonies ceased to be susceptible to 'phage attack after about 24 hours of incubation at 25°C., thus limiting the plaque size to the volume filled by 'phage diffusion within this time.

Both the number and size of the plaques were affected by the concentration of agar, the composition of the nutrients in the medium, the temperature of incubation, and the age of the bacterial suspension used for plating.

6. Kleczkowska, J. 1945. *A quantitative study of the interaction of Bacteriophage with* Rhizobium *using the technique of poured plates.* J. Bact., **50**, 81-94.

Using a bacteriophage derived from a strain of *Rhizobium* producing nodules on *Pisum* it was found that when suspensions of 'phage and of live susceptible bacteria are mixed, a constant percentage of the 'phage particles become attached to the bacteria. Dead bacteria and live bacteria that are resistant to attack by the 'phage attach to themselves a percentage of the 'phage particles which decreases with increasing 'phage concentration. When added to a young liquid culture of bacteria the 'phage begins to multiply within 45 minutes and does so until the culture is cleared.

The final concentration of phage particles is independent of the initial dose, but depends on the initial supply of bacteria ; it is also greatly affected by the age of the bacterial culture when infected with 'phage.

When a cleared culture of 'phage and susceptible bacteria is kept for some 5 to 6 days, growth of the bacteria may recommence. This secondary growth consists of susceptible bacteria or of new dissociant strains resistant to the 'phage.

The repopulation of the previously lysed culture by susceptible bacteria, growing in the presence of 'phage, is made possible by the appearance, during the process of lysis, of some substance that protects the bacteria against 'phage attack.

The resistant dissociant strains of bacteria resembled the parent forms antigenically and were as effective in nitrogen fixation within the host legume. They maintained their 'phage resistance after cultivation in the laboratory up to 2 years. They were readily produced in soil cultures of bacteria treated with 'phage.

When clover, grown aseptically, was infected with a pure culture of a *Rhizobium* strain susceptible to the 'phage, resistant variants appeared in the nodules in the absence of the 'phage.

Among the naturally occurring strains of *Rhizobium* that were tested, only a small proportion of strains of pea or clover nodule bacteria (10 to 15 per cent.) were found to be susceptible to the strain of 'phage studied.

7. Kleczkowska, J., Nutman, P. S. and Bond, G. 1944. *Note on the ability of certain strains of* Rhizobium *from peas and clover to infect each other's host plants.* J. Bact., **48**, 673-675.

The ability of certain strains of *Rhizobium* from clover to produce nodules on peas and of certain strains from peas to infect red clover has been confirmed by independent cross inoculation tests made at Rothamsted and at Glasgow. In these tests, strains were cross-inoculated two or three times and

after reisolation were found to agree in serological behaviour with the original cultures.

The formation of nodules on such cross inoculates, however, took place only to a limited extent, and, at least in the case of pea strains on clover, after an unusually long interval. In no case did the host plant derive visible benefit from the strain belonging to the other inoculation group. The fact that only certain strains will cross-inoculate may explain the disagreement in the findings of other workers.

8. KLECZKOWSKI, A. and THORNTON, H. G. 1944. *A serological study of root nodule bacteria from pea and clover inoculation groups.* J. Bact., **48**, 661-672.

Twenty-nine strains of nodule bacteria derived from plants of the pea inoculation group, and 161 strains derived from clover nodules, were tested for agglutination with antisera against six strains of nodule bacteria, four derived from clover and two from pea.

No antigen or set of antigens of either O or H type was found to be common to the whole group. Some strains reacted with none of the antisera, some with only one, and others with several antisera, but none with all of them.

Strains belonging to both inoculation groups were found to give agglutination with five of the antisera ; one antiserum reacted only with a small number of strains all from clover.

Neither ability to cross-inoculate between clover and pea host plants, nor effectiveness in fixing nitrogen within the host plant, nor susceptibility to a bacteriophage was necessarily associated with the presence or absence of any one antigen or group of antigens. Indeed, an effective strain and a very ineffective variant derived from it were found to be serologically identical.

There was, however, a partial correlation between effectiveness and the H antigenic constitution.

9. MEIKLEJOHN, J. 1940. *Aerobic denitrification.* Ann Appl. Biol., **27**, 558-573.

Two species of *Pseudomonas* are described, which reduce nitrate to nitrite and nitrogen gas in simple synthetic media. An adequate supply of a suitable organic compound is necessary for denitrification. Both species will denitrify in aerated, and in undisturbed aerobic cultures, as well as under anaerobic conditions.

At C:N ratio 10, the bacteria grow to higher numbers in aerobic than in anaerobic cultures. The amount of precipitable nitrogen retained in a culture is directly proportional to the bacterial numbers, and therefore the smaller loss of nitrogen from aerobic compared with anaerobic cultures is a consequence of the greater growth of the bacteria.

At pH 6·9 nitrite has a poisonous effect, proportional to its concentration, on both species ; but at pH 8·0 it is harmless and freely reduced.

10. MEIKLEJOHN, J. 1943. *The vitamin-B content of potatoes.* Biochem J., **37**, 349-354.

Using the *Phycomyces* method of estimation it was found that the vitamin B_1 content of Majestic tubers at the time of lifting (September) is about 140ug/100g.

During the growing season the vitamin B_1 content of tubers increases continuously up to the time of lifting of maincrop potatoes ; in stored tubers it falls during the winter and spring ; the greater part of the loss takes place in spring, and is apparently due rather to sprouting than to storage, especially as white sprouts have a higher vitamin B_1 content than the tuber which produced them. The content of young potato leaves is very high.

An adjuvant factor of undetermined nature is present in the centres of tubers between April and August, and always present in the skin layer.

Green sprouts completely inhibit the growth of the fungus.

11. MEIKLEJOHN, J. 1943. *Loss of thiamin from cooked potato.* Nature, **151**, 81.

In potato samples sterilised in liquid media at a pH of 6.4 by steaming for 45 minutes on three successive days it was found that from 2/3 to 3/4 of the thiamin present in the tubers was washed out into the liquid in the course of steaming.

12. NICOL, H. and THORNTON, H. G. 1941. *Competition between related strains of nodule bacteria and its influence on infection of the legume host.* Proc. Roy. Soc. B., **130**, 32-59.

Where two strains of nodule bacteria are both present in the surroundings of their host's root system, active competition between them may cause the strain having the higher initial growth rate almost completely to check multiplication of the other strain outside the plant. This dominant strain will then be responsible for nearly all the nodules.

In peas and soy beans, where growth of the root system is rapid and of comparatively short duration, the nodule-producing capacity of the plant may be partially or wholly satisfied by the nodules produced within the first few weeks, so that further infection, whether by the same or by a different strain, is checked or inhibited.

In clover, whose root system continues to grow over a long period, the first-formed nodules do not stop further nodules from being formed either by the same or by a different strain.

There are large differences in the rates of appearance and final numbers of nodules produced by different strains supplied in pure culture, particularly with clover.

The relative numbers of nodules produced by the two strains simultaneously applied to the roots is conditioned by the specific infectivity peculiar to each strain, unless some other factor, such as competition outside the plant, masks this effect.

13. NUTMAN, P. S. 1945. *A factor in clover nodule formation associated with the volume of the medium occupied by the roots.* Nature, **156**, 20.

The number of nodules formed on a clover plant growing on a limited volume of agar depends upon the presence of other plants in the same tube and the volume of the medium. The results of an experiment in which both the rate of sowing and the volume of the medium were varied show that the number of nodules per plant is inversely proportional to the number of plants sharing the same root space and directly proportional to the volume of the medium ; reduction of the volume of the medium to half being equivalent to doubling the sowing rate in effects on individual plant nodule number.

The simplest explanation that this specific volume relationship is due to direct competition for nutrients appears to be inadequate and it is suggested that reduction in nodule number may be due to the production of a nodule-inhibiting root secretion, the concentration of which varies with the plant number and volume of root medium.

14. NUTMAN, P. S., THORNTON, H. G. and QUASTEL, J. H. 1945. *Inhibition of plant growth by 2 : 4-dichlorophenoxyacetic acid and other plant-growth substances.* Nature, **155**, 497.

The toxic activity of β-indolylacetic and α-naphthylacetic acids on red clover grown under sterile conditions on agar is shown to be considerable, germination and growth being markedly affected by concentrations higher than 1 ppm. Under similar conditions and at higher concentrations tryptophane is also toxic ; its toxicity being increased by inoculation with nodule bacteria indicating that synthesis of indolylacetic acid from tryptophane occurs in the presence of nodule bacteria.

In sterile soil the toxicity of the above compounds is maintained but it is lost in unsterilised soil probably owing to microbial decomposition. Other growth promoting substances of the phenoxyacetic acid group, in particular 2 : 4-dichlorophenoxyacetic acid, are equal in toxicity to heteroauxin and also retain activity in soil for several weeks.

The activity of 2:4-dichlorophenoxyacetic acid is less in heavy Rothamsted soil than in light Woburn soil. The compound is water leached from soil with difficulty.

In soil wide differences in susceptibility appear between the plants tested (clover, wheat and sugar beet) suggesting that dichlorophenoxyacetic acid in minute amounts may be employed in weed control.

15. SINGH, B. N. 1941. *Selectivity in bacterial food by soil amoebae in pure mixed culture and in sterilised soil.* Ann. Appl. Biol., **28**, 52-64.

By using a plate culture method it has been shown that certain limax amoebae can select among five strains of *Aerobacter* the ones most readily

eaten, although the strains differ only in very minor respects. A wide range of bacterial species were also tested, of these some were completely uneaten, others readily eaten and others eaten to some extent. No distinction was shown between gram positive and gram negative forms. In sterilised soil inoculated with edible and non-edible species of bacteria the amoebae reduce the numbers of the edible species.

16. Singh, B. N. 1941. *The influence of different bacterial food supplies on the rate of reproduction in* Colpoda steinii, *and the factors influencing encystation.* Ann. Appl. Biol., **28**, 65-73.

The rate of reproduction in *Colpoda* varies considerably with the bacterial food supply, the age of the culture, the size of inoculum, and the metabolic products. The metabolic products of bacteria and Protozoa have a slight retarding effect on the rate of reproduction. There is no evidence of allelocatalysis in *Colpoda* either in isolated individuals or in mass cultures.

The resistant or " dauer " cysts are formed only when there is practically no bacterial food present in the culture solution or in the presence of unfavourable food supply. The metabolic products of bacteria and Protozoa have no influence on the formation of resistant cysts in *Colpoda*.

Excystation takes place even in dried cysts of more than 3 months in the presence of bacteria. No excystation takes place in such dried cysts when they are moistened with only soil extract without the presence of bacteria.

17. Singh, B. N. 1942. *Selection of bacterial food by soil flagellates and amoebae.* Ann. Appl. Biol., **29**, 18-22.

The food preferences of two soil amoebae and a soil flagellate, *Cercomonas crassicauda*, were compared as regards forty-eight strains of bacteria, which included a miscellaneous group mostly from soil, a group of *Rhizobium* strains and a group of plant pathogens. The amoebae were able to eat about half of the strains belonging to the miscellaneous group and most of the plant pathogens. Nearly all the strains of *Rhizobium* were inedible. The *Cercomonas* ate a rather larger number of strains than did the amoebae and differed from the large amoeba in its food preference as regards eleven out of the forty-eight bacterial strains. The plant pathogens that were inedible by amoebae produced an exo-toxin harmful to amoebae, but without apparent effect on *Cercomonas*, which could eat all these strains partly or completely. Slime produced by certain strains of the bacteria did not inhibit the feeding of the protozoa.

18. Singh, B. N. 1942. *Toxic effects of certain bacterial metabolic products on soil protozoa.* Nature, **149**, 168.

19. Singh, B. N. 1945. *The selection of bacterial food by soil amoebae, and the toxic effects of bacterial pigments and other products on soil protozoa.* Brit. J. Exp. Path, **26**, 316, 325.

Bacteria may be edible, inedible but harmless, or toxic to soil amoebae. In a survey of 103 bacterial strains it was found that those producing red, violet, blue, green or fluorescent pigments were not eaten by protozoa. The pigments of *Bacillus prodigiosus* and *Chromobacterium violaceum* are toxic to protozoa, as are the metabolic products of *Bacterium pyocyaneum*. The calcium salt of penicillin is not toxic to protozoa even in strong concentrations, while penicillic acid and citrinin seem to be toxic up to a concentration of 1/1,500.

20. Thornton, H. G. 1945. *Effective and ineffective strains of legume nodule bacteria.* Nature, **156**, 654.

A summary of work at Rothamsted as it touches upon the results obtained in Professor Virtanen's laboratory at Helsinki.

DEPARTMENT OF BOTANY

By Winifred E. Brenchley

In the Report for 1935 a survey was made of the work of the Botanical Department since its inception in 1906, and in the 1936-1938 reports certain completed investigations were outlined. It is now proposed to bring the account of the work of the Department up to date, including where necessary investigations that were in progress before war broke out.

Since 1935 the only major changes in the organisation of the Botanical Department have been a recent strengthening of the scientific staff and the provision of more adequate glasshouse accommodation. A new range of houses was completed in 1940 for the bacteriology, botany and chemistry departments, of which four houses with an adjoining potting shed, drying room, weighing room and bird-proof cage were shared by botany and chemistry, the water-culture and bacteriology glasshouses being under separate roofs. A glasshouse, preparation room and stills room are now available for water-culture work, the stills room being isolated to prevent the entry of gas fumes into the glasshouse, the distilled water being conveyed direct to carboys by glass tubes passing through the wall into the preparation room. The chief feature of the glasshouse is a range of shallow tanks 58 ins. by 27 ins. by 7½ ins. running down each side, each with a cold-water inlet and an overflow, providing for the immersion of culture bottles to control root temperatures. When not in use the tanks are covered with sliding wooden covers which make an ordinary bench.

Plant physiology

Work has continued on various minor elements and on other physiological problems. Boron is essential for the normal growth of carrots, and as death soon occurs in its absence it was necessary to grow plants with boron for a few months and then remove it from the nutrient solutions in order to determine the effect of boron deficiency on the flowering stages. Where the original supply of boron was small, deficiency symptoms soon set in, and death of the apices occurred before the formation of flowering shoots. Where more boron had originally been supplied the effect of the shortage was delayed and then flower-bearing shoots were developed, only to die from deficiency before maturing. All plants receiving boron continuously formed normal flowering shoots. Anatomical investigations showed that breakdown of the tissues, particularly those associated with the meristematic and vascular systems, is an invariable concomitant of a deficiency of boron. The type of abnormality appears to be very similar to that described for other plants (1).

At the request and with the financial aid of the Chilean Nitrate Corporation work was begun in 1938 on the physiological importance of the various minor elements that are always present in Chilean nitrate. Although the value of the contained boron was already recognised time was given to compare the effect of the natural nitrate with synthetic nitrate plus boron and other elements. The

Chilean nitrate used was a composite sample drawn from 4,800 bags in one shipment, and spectrographic and chemical analyses were made before use. Boron, iodine and potassium perchlorate were the chief alien substances present in the nitrate. Of these boron proved to be the most critical, being essential for all species tested, whereas the effect of iodine and perchlorate was only evident in a few cases and was not consistent in repeated experiments. Most of the species showed their need for boron by making very little growth in its absence, Chilean nitrate being as effective a source of supply as sodium nitrate with added boric acid. Cereals and grasses, however, do not exhibit boron deficiency in the early stages but may make vegetative growth of an abnormal type, producing no ears as in barley, or may push up to ear as in oats, but fail to develop fertile grain.

The range of plants tested covered various cereals, leguminous crops, roots and leafy plants, giving information relative to most of the types of agricultural crops grown in this country. In all cases death of the growing point in the absence of boron was characteristic, and the development of red colouration or bronzing was noticed in several plants, as cauliflower, mangold and red clover.

While the essential nature of boron was so clear, only occasional evidence was obtained of a definite action of iodine, whether beneficial or otherwise. Sometimes an improvement was noticed in parsley when iodine was supplied, but this was not always seen. In soy bean the perchlorate present in the Chilean nitrate caused slight damage to some of the developing leaves, but no real depression of growth occurred and the dry weight was not affected. Attention was concentrated on an attempt to determine whether iodine is essential to plants, as it is sometimes assumed that because the element is now known to be necessary to animals it must therefore be needed by plants. Twenty-six species were tested, but in the majority of cases the value of iodine proved negative, causing no improvement in dry weight or appearance. Sometimes transient indications of benefit or depression occurred, but disappeared afterwards as growth levelled up. Any variations in dry weight at harvest were usually not much beyond the limits of experimental error. There seems to be little evidence of a beneficial action of iodine over a fair range of plants, but the fundamental difficulty exists that the element is so widely distributed in air as well as in nutrient salts and water, and only experiments that can be carried out in iodine-free air can show definitely whether very minute traces of the element are indeed essential. Attempts were made to grow *Lemna* under such conditions, but as far as the experiments went they provided no further evidence.

Lettuces grown with Chilean nitrate were usually better than those receiving synthetic nitrate reinforced with boron and iodine, and traces of the other minor elements contained in Chilean nitrate were therefore tested, including molybdenum, titanium, strontium, vanadium, chromium and zinc. Of these only *molybdenum* gave very definite results, and plants receiving it were outstanding on account of their deep green colour, large size and relative freedom from disease (2). The importance of these results, if confirmed, from

the horticultural point of view led to intensive work being undertaken, but the results were variable and it is still impossible to say what conditions enable molybdenum to exercise a beneficial action. Among the factors examined were the range of concentration of molybdenum, the effect of different nutrient solutions, the possible correlation with the presence or absence of other minor elements, and the effects of the variety and the season of the year at which the plants were grown. Variable results were obtained throughout, in some cases improved plants being obtained with molybdenum, whereas in others the controls were just as good (3). The results are now being critically examined in search of any possible clue to this erratic behaviour.

Soil cultures show similarly variable results. Earlier work in the department had shown the toxicity of certain strengths of molybdenum for tomatoes, but in this later work the plants were able to stand heavy dressings without damage, and apparently also without any regular benefit. Further investigation showed that a soil factor is concerned here, as on a series of eight soils tomatoes were killed or seriously damaged on a Fen soil, but were quite healthy on the others. Flax, on the contrary, was seriously injured on five of the soils, while *Solanum nodiflorum* was still more irregular, as duplicates with the same treatment reacted differently, one sometimes being badly poisoned while the other was normal or only slightly damaged. It is hoped to continue this line of work, as it has very suggestive possibilities.

At the request of the Agricultural Research Council experiments were made to determine the effect of minor elements on the growth of flax. The problem of securing an adequate iron supply seems to be the focal point of difficulty in growing flax in water cultures, but very satisfactory growth was obtained with one of van der Crone's solutions.

The need of flax for *boron* is beyond question, but the plant seems to be responsive to very small amounts, which, as with other species, must be available throughout life. One part of boric acid in 100,000,000 parts of nutrient solutions will support healthy growth for a time, but as the plant develops this supply becomes inadequate and deficiency symptoms appear. Signs of toxicity occur when the concentration of boric acid ranges about 1 : 10,000. The question of boron deficiency and toxicity is affected by the amount of boron available at any one time, and also by the total amount presented during the entire life of the plant. This means that a weaker concentration applied frequently may be as effective as a stronger one given at longer intervals, provided the total quantities of boron are equivalent. On the other hand a heavy dose given at one time may have a toxic action, whereas the same quantity given at intervals may have excellent results.

No indication was obtained that *zinc* is essential for the growth of flax, but there was a slight suggestion that toxicity might begin to occur with zinc sulphate about the range of 1 : 5 million concentration.

By the courtesy of the Norfolk Flax Establishment fibre estimations were made of flax plants grown in soil with different manurial combinations and at different rates of sowing. In the soil

used, nitrogen was the only manure which increased the yield, potash, phosphate and sodium chloride having no such influence when applied singly or together.

In 1943, the fibre content was increased by the use of phosphate especially when combined with potash, whereas nitrogen lowered the percentage. A larger proportion of fibre occurred in the thinner straws from densely sown pots than in the thicker ones from well spaced plants. The next year the same effect of phosphate was obtained, the lowest level of phosphate tested always giving the best result, as heavy dressings caused a considerable drop in the fibre content except where sodium was also present. When nitrogen was applied the fibre content was at a consistently low level, though this might not necessarily hold good on all soils.

X-RAY TREATMENT OF SEEDS

Seeds of wheat and barley, both dry and soaked, which had been treated with hard or soft X-rays were grown and brought to maturity in pot cultures in Rothamsted soil. Preliminary findings in germination tests were borne out by the results of the long-term experiment. Treatment in the dry state had little effect on growth, though there was a suggestion of an approach to the toxic limit with hard X-rays on wheat.

Soaking the seeds renders them much more susceptible to both types of ray, the hard rays being the more harmful, and barley being more adversely affected than wheat. With barley the three highest dosages of both types of ray killed all the seeds, the weakest hard X-rays killed most and depressed the others while the weakest soft X-rays gave variable results, with a general tendency to decreased ear development. Wheat showed a more variable response to treatment, as with the soft rays some plants survived all treatments and developed remarkably well, the weakest dose causing little or no depression. With hard rays the weakest dose had a similar effect, but with higher dosages only one plant developed, adversely affected in development and rate of maturity.

In no case was there any indication of stimulus due to seed treatment, as far as could be told from the green weights. One noteworthy feature of the results was the lack of gradation in the effect of treating soaked seeds, as in nearly all cases such seeds were either killed or left relatively undamaged, very few plants showing injury which increased progressively with the strength of treatment.

The seeds from these first crops were sown the next season, but no definite evidence was obtained that the treatment of seed with X-ray affects the resultant grain in any way that is shown in the succeeding crop. With barley the only suggestion of a beneficial after-effect was with the dosage of 7,000 " r " units of either hard or soft rays on seeds treated dry, the straw being more abundant, but without any corresponding grain increase, but there were insufficient data to decide whether this was really the result of treatment or merely an accidental coincidence. The general conclusion reached was that any harmful effects of X-ray treatment are not passed on to the next generation and that no suggestion of transmitted beneficial action was forthcoming.

Vitality of buried weed seeds

The sectional fallowing of Broadbalk field that was carried on for two-year periods between 1925 and 1929 proved very successful in reducing the weed-seed population of the soil, but with the first year that the whole field returned into crop it became evident that many of the weed species would soon reassert themselves and become as prevalent as they were originally unless some definite method of control were instituted. A cycle of fallowing was therefore started in 1931, in which one of the five sections of the field was fallowed each year in succession, so that the whole field was in fallow for one year in five. After this cycle had been repeated twice the results were worked up for publication, but the benefit was so obvious that the method is still being continued as a matter of farm routine. During the first ten years twenty samples were taken yearly from each of the three plots receiving farmyard manure, minerals and sulphate of ammonia together, and minerals and sulphate of ammonia in alternate years. This yearly sampling was then discontinued, but another series of samples has been taken this year (1945) after harvest to enable a comparison to be made with the position in 1940 at the end of the last five-year cycle.

As before, the samples were reduced in bulk by washing through sieves, and the seedlings that appeared over a period of three years were counted and removed. The numbers of seedlings obtained were grouped to show the reduction in weed-seed population during fallow and the behaviour of the various species during the succeeding years in crop. By this composite grouping several years' results are included in each figure, and the effect of variable seasonal and cultivation factors is greatly reduced.

The buried seeds of most species are reduced by fallow, and increase more or less rapidly during succeeding years, only to be again reduced by a later fallow. Usually this reduction brings the population to a lower level than after the first fallow. Black bent (*Alopecurus agrestis*) varies from year to year more than any other species. Poppy (chiefly *Papaver rhoeas*) was the outstanding exception to the general rule, as, once reduced by fallow, it usually failed to reassert itself and was again reduced by a later fallow. Consequently, this species is no longer the menace that it was in 1925 when the experiment first began, and poppies are now very little in evidence. About ninety per cent. of the total seedlings that germinated consisted of black bent, poppies, lady's mantle (*Alchemilla arvensis*), field speedwell (*Veronica arvensis*) and black medick (*Medicago lupulina*).

The production of weed seeds was much influenced when minerals and sulphate of ammonia were applied alternately. With most species nitrogen encouraged heavier seed production, as was shown by the average number per section compared with those produced with mineral manuring. Field speedwell was the only one of the main species to behave irregularly with the two types of manuring, and black medick was the only one to respond in a reverse direction, being more benefited by minerals than nitrogen.

In the first year after fallowing both crop and weeds were usually able to profit by the stored fertility, and did not appear to come into competition with one another except where farmyard

manure was used, when the heavy growth of the crop at first kept the weed-seed population of the soil down to a low level. In later years the crop tended to become less heavy, and the weeds increased to correspond, until the balance was again restored by another fallow.

Field observations have been carried on alongside the laboratory experiments, and have shown a steady improvement in the cleanness of Broadbalk field, confirming especially the reduction of poppies. The various weed species fall into definite groups, according to whether the increase or reduction in numbers induced by fallowing is maintained, or whether there is an irregular increase or decrease in numbers over a term of years (6).

The general conclusion is that the fallowing of one section per year has fully justified itself, as the weed-seed population has not only been kept in check, but has also been decreased during the fifteen years that the system has been applied.

In spite of the periodic fallowing, however, an infestation of wild oats has recently attacked certain parts of Broadbalk field, and is also troublesome on Hoos, threatening to become serious if some means are not found to check it. Several species and varieties of wild oats are involved, and investigations have been put in hand to gain more knowledge of the habits and dormancy of these weeds, with a view to attacking them in the best way, and at the most vulnerable time in their life history. This is bound to take some time and meanwhile various direct methods of attack are being considered. As wild oats are also prevalent at Woburn, on an entirely different type of soil, close contact is being kept with Dr. Mann on the matter.

Grassland

Since the publication of " Manuring of Grassland for Hay " in 1942, a considerable amount of analytical and observational data on the flora of the Park Grass plots has accumulated, some of which have been utilised in various papers. During the war it has not been possible to deal with this material, but it is now hoped to consider it in detail and to bring the ecological history of the plots up to date. Since 1940 complete botanical analysis into individual species has had to be suspended owing to pressure of other work, but will be resumed if required to clear up any points that may arise during the examination of the accumulated material.

In connection with the grazing experiments on High Field, to test the effect of combined slagging and manuring of the pasture as shown by the growth of cattle and sheep, botanical analyses of the herbage have been made each year. Early in the season, before the beasts are put on, a number of cages are distributed on each plot, and kept there till the grass is high enough to be identified easily. Then a two-foot square of grass is cut from each protected piece of herbage, and dried in the shade to keep its colour, afterwards being analysed into its constituent species. A year after the first application of slag there were indications that rather more white clover had been encouraged on the slagged areas, though variations between different parts of the field were very great. Visual observations during the spring of 1939 confirmed this, as it was possible

for an impartial observer to pick out the slagged areas by the extra growth of white clover on them. Grouped analytical figures from the samples indicated that this increase was maintained when the growing period arrived. An additional dressing of slag was then applied across the original treatments of the plots, and the analyses have been continued year by year, though all the data have not yet been worked up.

Joint investigations

During recent years a considerable amount of work has been done in conjunction with other departments, and accounts of this will be found in the reports of the departments concerned.

During the war, work has been carried on in co-operation with the chemical department in pot cultures with a variety of organic fertilisers, using spinach beet as the chief subject, with some tests on turnips. In this connection a large number of boiling tests were made on potatoes, a special technique being developed for the purpose.

In 1944 the Farm collaborated in a number of small-scale spraying tests with various recognised weed-killers, with the primary idea of ascertaining their effect on different crops, rather than their action on weeds, which was already well known.

Experiments have now been started together with the Crop Physiology Department on the relation between potash and sodium nutrition in sugar beet, using the method of sand cultures. The results of the first year's tests justify carrying on the work if the departmental programmes permit.

PUBLICATIONS

SCIENTIFIC PAPERS

1. Warington, K. 1940. *The growth and anatomical structure of the carrot* (Daucus carota) *as affected by boron deficiency*. Ann. Appl. Biol., **27**, 176-183.

Carrots grown in nutrient solution without B were unable to develop normally and exhibited both external and internal deficiency symptoms. The effect of a lack of B on the flowering stage was determined by transferring plants to a B-free solution after they had received an initial supply. The chief deficiency symptoms were :—

(*a*) *External*. The leaves curled back pointing downwards, the laminae often being reduced, and the growing apex of the shoot died. The tap root was small with abnormally thickened laterals and sometimes wart-like excrescences on the outside. If the flowering stage was reached, before the deficiency arose the inflorescences bent over and died, those on the side shoots succumbing first.

(*b*) *Internal*. Most of the tissues of both shoot and root were affected before external deficiency symptoms appeared. Breakdown began in the region of the growing point of the shoot though the meristematic apex was not necessarily first involved. Lesions preceded or accompanied by hypertrophy occurred in the cortex and less frequently in the pith. All components of the vascular bundles were affected, blocking occurring in the xylem and phloem and hypertrophy and breakdown in the thin-walled tissues. The formation of wart-like growths and the thickening of the lateral roots was due to repeated branching and radial extension after elongation and emergence were prevented through death of the apices.

2. BRENCHLEY, W. E. and WARINGTON, K. 1942. *Value of molybdenum for lettuce.* Nature, **149**, 196.

A preliminary note on the beneficial effect of 0·1 p.p.m. Mo as sodium molybdate on lettuce grown in nutrient solution indicated that treated plants were both larger and a richer green colour than the untreated controls, and appeared to be less susceptible to disease.

3. BRENCHLEY, W. E. 1943. *Trace elements in Chilean nitrate.* Manufact. Chem., **14**, 5-6.

Experiments carried out in nutrient solutions have given fresh support to the view that Chilean nitrate is not only valuable as a nitrogenous fertiliser, but also on account of its content of minor elements, especially boron, iodine and molybdenum. This was demonstrated on a wide range of crops, including grasses, legumes, roots and leafy plants. In some cases molybdenum improves the growth of lettuce, but this does not always occur and the necessary conditions are not yet known. There is still no evidence that iodine is essential to plants, but the possibility is suggested that by dressing with Chilean nitrate the iodine content of plants may be increased, to the benefit of animal and human consumers.

4. BRENCHLEY, W. E. 1943. *Minor elements and plant growth.* Biol. Rev., **18**, 159-171.

5. BRENCHLEY, W. E. 1946. *Recent work on minor elements and crop growth.* Bot. Rev. In the press.

These two reviews follow up that published in the Botanical Review in 1936, and attempt to epitomise the chief work on minor elements in relation to plants up to the present time. The voluminous literature on the subject only allows of a bare outline of the work, and the references, selected out of many thousands published, indicate as far as possible where additional information can be obtained by those interested in any special aspects of the subject.

6. BRENCHLEY, W. E. and WARINGTON, K. 1945. *The influence of periodic fallowing on the prevalence of viable weed seeds in arable soil.* Ann. Appl. Biol., **32**, 285-296.

Soil samples were taken annually for 10 years from three plots on Broadbalk permanent wheat field to determine the effect of a sectional cyclic fallowing once in five years on the control of weeds. The plots selected received farmyard manure, minerals and sulphate of ammonia together, and minerals and sulphate of ammonia in alternate years. Most species are reduced by fallow, rise more or less rapidly during succeeding years, and are again reduced by a later fallow, usually to a lower level than the first. *Alopecurus agrestis* showed the greatest variation from year to year. *Papaver rhoeas* was the outstanding exception to the general rule, as, once reduced by fallow, it failed to reassert itself except in a few cases, and was further reduced by the later fallow. These two species, with *Alchemilla arvensis*, *Veronica arvensis* and *Medicago lupulina*, contributed about ninety per cent. of the total seeds.

Alternate manuring with minerals and sulphate of ammonia greatly influenced the production of weed seeds, nitrogen inducing the heavier seed production with most species. *Alopecurus agrestis*, *Alchemilla arvensis*, and usually *Papaver rhoeas* responded thus, *Veronica arvensis* was the only one of the main species to behave irregularly, whereas *Medicago lupulina* showed a reverse response, being more benefited by minerals than nitrogen. The various weed species fall into definite groups, in two of which the reduction or increase in numbers induced by fallowing is maintained, while in the third there is an irregular increase or decrease over a period of years. The general conclusion is that the fallowing of one section per year has fully justified itself, as the total weed seed population has not only been kept in check, but has been gradually decreased during the fifteen years the system has been applied.

TECHNICAL AND OTHER PAPERS

7. BRENCHLEY, W. E. 1937. *Boron and the control of plant disease.* Nature, **139**, 536-537.

8. BRENCHLEY, W. E. 1942-3. *Botanical investigations at Rothamsted. 2. Minor elements and plant growth.* Proc. Linnean Soc., Session 155, 238-240.

This paper formed part of a symposium on botanical work at Rothamsted given at the Linnean Society in celebration of the Centenary of the Experimental Station.

9. BRENCHLEY, W. E. 1943. *Development of botanical investigations at Rothamsted.* Nature, **152**, 91.

10. WARINGTON, K. 1944. *Boron in relation to plant life.* Article written at the request of the M.O.I. for inclusion in a Russian Technical Journal.

An account is given of the gradual development of knowledge regarding the importance of boron to plant life and its practical application. Starting from the discovery of boron as a constituent of plant ash, scientific investigations are traced through the period when the addition of minute quantities of the element were found to be beneficial up to the discovery that the element is essential for some of the higher plants. Examples are given of the practical application of this discovery in the association of boron deficiency with various crop diseases, the cause of which had previously been unknown. The effect of boron deficiency on the structure and metabolism of the plant is discussed and some references made to the theories as to the function of the element.

11. BRENCHLEY, W. E. 1945. *Trace elements in relation to plant growth.* South Eastern Naturalist & Antiquary, **50**, 6.

Presidential address to the Botanical Section of the South Eastern Union of Scientific Societies, at Rothamsted 1945.

12. BRENCHLEY, W. E. 1937. *Pasture problems.* Nature, **140**, 918-919.

13. BRENCHLEY, W. E. 1938-9. *The vitality of weed seeds.* Proc. Linnean Soc., Session 151, 145-152.

14. BRENCHLEY, W. E. 1940. *The weed problems in non-rotational wheat-growing.* Emp. J. Exp. Agric., **8**, 126-137.

A résumé of the results of fallowing on the weed flora of Broakbalk Wheat Field.

15. BRENCHLEY, W. E. 1940. *Weed seeds in the soil.* Rothmill Quart. Mag., **11**, 177-181.

16. BRENCHLEY, W. E. 1944. *Weed control and the dormancy of weed seeds.* Agriculture, **50**, 452-455.

The above group of papers (13-16) outline various aspects of the vitality of weed seeds in relation to the problem of weed control in agriculture.

17. BRENCHLEY, W. E. 1944. *The behaviour and survival of weed seeds in cultivated land.* School Nature Study, **39**, 2-4.

18. BRENCHLEY, W. E. 1944. *Weed control by chemical methods.* Manufact. Chem., **15**, 426-431.

Although herbicides have for long had a limited use for destroying all vegetation on railway tracks, paths, tennis courts and other areas, the interest which is at present being shown in the subject reflects tendencies in agriculture which have made labour scarce and costly and introduced intensive, mechanised methods of cultivation. The essential difference between the old and the new view of herbicides is that they shall be selective in their action, killing or retarding weeds while leaving crops unharmed, or even directly nourishing them. Each of the chemicals so far used for this purpose has its special merits, limitations and mode of use, and there is coming into being a fairly complex technique of choosing and applying weed control chemicals for their effect on specific crops and in specific conditions

Reviews, all by W. E. BRENCHLEY.

19. ELLIS, C. and SWANEY, M. W. 1938. *Soil-less growth of plants*. Pages 155, plus 1 plate. 13/6 net. Nature, **142**, 649-650.

20. KORSMO, E. 1939. *Weed plates, Series* 3. Plates 61-90. With textbook of 140 pages. Nature, **143**, 1,003.

21. GUISE, C. H. 1939. *The management of farm woodlands*. (American Forestry Series). Pages 352. (McGraw-Hill Book Co.). Price 20/-. Nature, 1940, **146**, 475.

22. *Hunger Signs in crops*. 1941. Pages 327, illustrated. Published by the American Society of Agronomy and the National Fertiliser Association. Nature, **148**, 330.

23. ROBBINS, W. W., CRAFTS, A. S. and RAYNOR, R. N. 1942. *Weed Control*. Pages 543. (McGraw-Hill Book Co.). Price 35/-. Nature, 1943.

24. ALLPORT, N. L. 1943. *Chemistry and pharmacy of vegetable drugs*. (London. George Newnes, Ltd.). Pages 264. Manufact. Chem., 1944, **15**, 108.

SECTION OF CROP PHYSIOLOGY

By D. J. Watson

Field experiments

The Section has continued to act as a link between the farm and the laboratories, and has been responsible for the preparation of detailed plans of field experiments, and the general supervision, from the laboratory side, of the conduct of the experiments. The problems investigated in the field experiments are discussed on page 233.

New summaries have been prepared (1, 2, 3) of the results of the Broadbalk, Hoosfield and Barnfield classical experiments, including the data accumulated since the last account of the experiments was published in 1905, and the results of the many statistical investigations made on the data in recent years.

Problems arising from the war

(*a*) *Damage to crops by war gases and by incendiary action*

On the outbreak of war, the possibility of damage to growing crops by enemy action had to be faced. Deliberate attack on crops seemed improbable, but it was thought that serious losses might occur in the course of operations against other objectives. Of the possible methods of attack, the one most likely to cause damage over large areas was considered to be the spraying of the persistent vesicant gases, mustard gas and lewisite, from aircraft. Accordingly an investigation was begun in 1940 in collaboration with the Chemical Defence Research Station, Porton, on the effect of these substances on the more important agricultural crops. In connection with this work, Sir John Russell and D. J. Watson served on the Crop Sub-Committee of the Chemical Board of the Ministry of Supply.

The objects of the work were :

(1) to discover the immediate visible effects of mustard-gas and lewisite spray on growing plants, for the purpose of diagnosing the presence of contamination ;

(2) to measure the loss of yield caused by contamination at different stages of growth ;

(3) to determine how long toxic effects, which would render crops unsafe for use as food, persist after contamination ;

(4) to work out appropriate methods of treating contaminated crops, and of utilising or disposing of the produce.

A series of field experiments was carried out in 1940, in which mustard-gas and lewisite spray, simulating in drop size and concentration the spray from high-flying aircraft, was deposited on a variety of crops at different stages of growth. Observations were made on the immediate effects of contamination and on the effects on subsequent growth and yield. The toxicity of the contaminated plants at intervals after spraying was determined by feeding experiments with rabbits. The results varied greatly with the crop, ranging from complete destruction to the absence of any permanent injury. Mustard gas usually caused only localised injury at the site of contact with spray drops, and toxic effects were of short duration

except when the temperature was very low. Lewisite readily penetrated into plant tissues, and caused more extensive scorching of the foliage. It tended to spread along the vascular tissue, and in this way caused necrosis in underground parts of the plant, such as potato tubers and the storage root of sugar beet. Affected tissues were shown to have a high arsenic content and were permanently toxic.

Mustard-gas vapour caused proliferation of the tissue of the above-ground portion of the storage root of sugar beet, producing tumour-like growths similar in appearance to those caused by the bacterial disease " crown-gall." It also affected the apical buds of potato stems, leading to deformation of the leaves subsequently produced.

The germination of wheat and barley grain from contaminated crops was only slightly affected. Pot experiments in 1941 showed that such grain could safely be used for seed, and with very few exceptions produced plants which were normal in growth and yield. It was also found that potato tubers affected by internal necrosis caused by contamination of the growing crop with lewisite were suitable for use as seed : they gave a slightly higher yield than tubers from an uncontaminated crop grown from the same stock of seed, probably because the destruction of the haulms by lewisite had reduced the spread of leaf-roll infection. Although the necrotic tissue in these tubers was toxic to rabbits, only a small part of the volume of each tuber was affected, and the tubers were fed, either raw or boiled, to pigs, as part of a balanced ration without causing ill effects.

A summary of the results and recommendations was issued to Agricultural Advisory Officers and Civil Defence authorities in 1941 (7).

The problem of how to deal with grain stored in bulk, in the event of its becoming contaminated by a gas-bomb burst, was raised by the Ministry of Food, and an investigation was made of the particular case of barley and malt, large stocks of which are held at maltings (8, 9). It was suggested that the contaminants might be removed by volatilisation, by heating the grain in a malting kiln. An experimental kiln was constructed to provide conditions of temperature and ventilation similar to those used in a malting kiln. It was found that heat treatment followed by a period of storage was successful in removing all but a trace of mustard gas from both malt and barley, and fully restored the ability of the barley to germinate. The method failed when the contaminant was lewisite.

Precautions also had to be taken during the war against loss of standing corn crops by fire, started either by incendiary bombs aimed at built-up areas, or possibly by agents specially designed for igniting crops. Warnings to farmers were broadcast on nights when fire hazard was thought to be especially great, owing to favourable weather conditions. In the summer of 1941 experiments were undertaken at the request of the Ministry of Home Security to investigate the change in water content of cereal straws during ripening and its relation to weather factors, and to determine the critical water content at which ripening straw becomes inflammable, with the object of assessing the fire-hazard accurately from a knowledge of the progress of ripening and the weather forecast.

The season was very unfavourable for the work, for there was frequent rain during July and August, and the corn harvest was much delayed. Laboratory tests showed that wheat and barley straws become inflammable, in the sense that a flame is propagated indefinitely along the straw, when the water content falls below about 30 per cent. As it was found that the water content of the straw, especially near to the ground, when the grain was fit for harvest, was not greatly below and sometimes much above 30 per cent., it was concluded that the danger from fire had been over-estimated. This was confirmed by direct tests on field crops and the work was not continued.

(*b*) *The storage of potatoes in clamps*

At the beginning of the war, potatoes became one of our most important staple crops, and production was greatly increased by expanding the acreage grown. The proportion of the harvested crop which becomes available for human consumption depends on how much is lost during storage, and it was soon found that the wastage was high, especially as potatoes had to be held in storage until much later in the season than in peace time, owing to the cutting-off of supplies of imported new potatoes. It was recognised that the main causes of loss of weight during clamp storage were tuber diseases (especially blight), frost damage, loss of water and loss of dry matter by respiration and sprouting, but there was little information on the relative magnitudes of the losses due to different causes or on the rate of increase of wastage with time of storage. In 1942 the Agricultural Research Council set up a Conference on potato wastage to discuss these problems and arrange for experimental work on the causes of wastage, and its prevention. The Section was concerned with part of this work, in collaboration with the Biochemical Section, the Plant Pathology Department and members of the staff of the Midland Agricultural College.

In 1942 and 1943 experimental clamps divided into weighed sections were set up. At monthly intervals from January to July one section of each clamp was opened, the weights of sound tubers remaining and of sprouts, damaged tubers and debris were determined, and an examination of the rotted tubers was made to identify the pathogens causing rotting. It was found that the losses due to evaporation and respiration greatly exceeded the sprouting loss. The loss of weight increased slowly until April, and then much more rapidly during May and June : it was greatly increased in clamps from which the soil cover was removed in April.

Estimations of dry matter, sugars, starch, total nitrogen and ascorbic acid were made on samples taken at each occasion of opening the clamps. It was found that the major part of the change of fresh weight during storage was due to water loss. About 16 per cent. of the dry matter was also lost from the tubers by early July, almost entirely at the expense of starch, and 5 per cent. was recovered in the sprouts. The additional fresh weight lost in the clamp from which the soil cover was removed in April consisted entirely of water. Sugar content fluctuated, apparently in accordance with temperature changes, until the onset of sprouting when it tended to rise. Total nitrogen content per cent. of dry matter varied little : by the end of July about 10 per cent. of the

nitrogen originally present in the tubers had passed into the sprouts. Ascorbic acid rose to a maximum at the time when sprouting began, subsequently falling to very low values at the end of the storage period.

A study of the micro-climate of a potato clamp was begun ; continuous records of the temperature at various points in the potatoes and in the clamp coverings were obtained, and analyses of the internal atmosphere were made at intervals. Both temperature and CO_2 records gave evidence that in some conditions there was mass flow of air through the soil cover of the clamp caused by wind pressure on the clamp face.

A search was made for volatile chemical substances which would inhibit the sprouting of potatoes, without damaging or tainting the tissues of the tuber. Loss of weight and deterioration of quality due to sprouting after prolonged storage might be reduced by the use of such substances in clamps. Some 50 compounds were tested and a number gave promising results in laboratory tests, but attempts to use them in clamps met with little success, possibly because the permeability of the clamp covers to wind, noted above, prevented the maintenance of an effective concentration of vapour.

Physiological studies

Studies on the growth of field crops have been in progress for several years, with the object of relating variations in yield to physiological attributes of the crop, particularly net assimilation rate and leaf area. The work continued in 1939 with studies of the effect of varying nutrient supply over a wide range, using material from the classical experiments, and of the effects of sodium and potassium salts on the growth of sugar beet in 1942 and 1943. Pressure of work on the more urgent problems already discussed has delayed the statistical analysis of the large amount of data collected, but this is now being completed. The results showed that differences in dry-matter accumulation in a range of crops, seasons and nutritional conditions were usually the result of variation in leaf area ; variation in net assimilation rate played a minor part. It follows that a knowledge of the internal factors which affect leaf growth and determine leaf size is essential for the further analysis of agricultural yield.

Work on one aspect of this problem was begun in 1944, on excised stem tips of rye embryos, grown in sterile culture in darkness (6). This form of culture makes possible a study of the chemical factors concerned in leaf growth, independently of their effect on root growth. It was found that limited growth of the first leaf occurred, by extension of previously formed cells, if sucrose and mineral salts were supplied. A large number of substances, known or claimed to have growth-promoting effects on plant tissues were tested, but none of these increased the growth of the first leaf, and some had inhibiting effects.

During 1945 work has been done, in collaboration with the Botanical Department, on the effect of sodium salts on sugar beet at varying levels of potassium supply in sand culture, and in collaboration with the Plant Pathology Department, on the effect of infection with Yellows virus on the growth of sugar beet in field conditions.

PUBLICATIONS

SCIENTIFIC PAPERS

1. Russell, E. J. and Watson, D. J. 1939. *The Rothamsted field experiments on barley, 1852-1937, Pt. III. The composition and quality of the barley grain.* Emp. J. Exp. Agric., **7**, 193-220.

2. Russell, E. J. and Watson, D. J. 1940. *The Rothamsted field experiments on the growth of wheat.* Imp. Bur. Soil Sci., Tech. Commun. **40**.

3. Watson, D. J. and Russell, E. J. 1943-5. *The Rothamsted experiments on mangolds, 1876-1940.*

   Part I. 1943. *The effect of manures on the yield of roots.* Emp. J. Exp. Agric., **11**, 49-64.
   Part II. 1943. *Effect of manures on the growth of the plant.* ibid. **11**, 65-77.
   Part III. 1945. *Causes of variation of yield.* ibid. **13**, 61-79.
   Watson, D. J. 1946.
   Part IV. The composition of the mangolds grown on Barnfield. ibid. **14**, 49-70.

The above three papers are critical summaries of the results of three of the classical experiments, started by Lawes and Gilbert, and still continuing. The last previous account of these experiments was given by A. D. Hall in 1905 in his " Book of the Rothamsted Experiments," and the present papers bring this up to date. They also include, for comparison, discussions of the results of similar experiments at Woburn, and of experiments carried out by modern methods at Rothamsted and other centres in recent years.

Much of the information is drawn from papers published during the past 25 years on the results of statistical investigations of the data from the classical experiments, but the results of studies on other aspects of the data, hitherto unpublished, are also included.

The following are among the many topics discussed : the effect of manurial treatment on the growth and yield of the crop, including comparisons of different forms of nitrogenous fertiliser, the effect of farmyard manure and rape cake, the effect of potassium and sodium salts and their interaction with nitrogenous fertilisers ; seasonal variation of yield, and its relation to soil deterioration, weather conditions, plant population, and date of sowing ; seasonal variation in the response to fertilisers, and its relation to yield and to weather factors ; the effect of manurial treatment on the composition of the harvested crop ; seasonal variation in composition and the influence of climatic conditions ; the effect of fallowing on crop yield and weed infestation ; diseases and pests ; the effect of cultivation treatments on crop yield.

4. Watson, D. J. and Norman, A. G. 1939. *Photosynthesis in the ear of barley, and the movement of nitrogen into the ear.* J. Agric. Sci., **29**, 321-46.

Experiments were made in 1936 and 1937 on barley plants grown in pot culture, to determine the effect of shading the ear or the shoot after ear emergence on dry weight and nitrogen content.

It was found that after ear emergence the ear and the shoot (leaves and stem) make approximately equal contributions to the assimilation of the whole plant. In the 1936 experiment 28 per cent. of the final dry weight of the ear was accounted for by assimilation in the ear itself, and in the 1937 experiment, 19 per cent. These are minimum estimates, for assimilation must have been proceeding in the ears during emergence, before the shading treatments were applied. The results agree well with similar estimates of the extent of assimilation in the ear made on wheat by other workers.

The effects of shading on the amount of nitrogen present in the plant at harvest were somewhat variable, but they were always small compared with the effects on dry weight. Shading tended to reduce the amount of nitrogen in the ear, but as the dry weight of the ear was reduced to a much greater extent, nitrogen as percentage of dry matter in the ear was increased. It is concluded from this result that translocation of nitrogen compounds to the ear is not closely dependent on the amount of the concurrent increase in dry

weight of the ear. It appears that the approximate constancy of nitrogen percentage in the ear and grain throughout development is a consequence of the particular conditions prevailing during normal growth in the field.

The experiments showed that 20 to 30 per cent. of the dry weight of the whole plant was added after ear emergence, suggesting that climatic conditions during this late stage of growth is of considerable importance in determining the final yield.

5. WATSON, D. J. 1939. *Field experiments on the effect of applying a nitrogenous fertiliser to wheat at different stages of growth.* J. Agric. Sci., **29**, 379-98.

An account is given of the results of two series of field experiments carried out at Rothamsted and Woburn in the years 1926 to 1936 on the effect of nitrogenous fertilisers on wheat. In the first series a comparison was made of the effects of early (March) and late (May) top-dressings, and in the second series a range of times of application from sowing to the end of May were tested.

At Rothamsted, the increases of yield of grain produced by the nitrogenous fertiliser were small and rarely significant, but they were greater at Woburn. On the average of all experiments, the effect of the fertiliser on yield of grain was independent of the time of application. In individual years, variation in effectiveness between times of application was found, and this was correlated with the amount of rain falling in a short period after the time of application. At Woburn, the effectiveness of the fertiliser decreased with increase in the amount of rain falling immediately after the application of the fertiliser, but at Rothamsted the effects were less clear and appeared to be in the opposite direction.

The effects on straw yield were relatively greater, and more consistent, than those on grain yield. A greater increase of straw yield was produced by early top-dressing (January-March) than by application at the time of sowing, and the increase declined steadily the later the time of top-dressing. Shoot height was increased by the nitrogenous fertiliser, and varied with time of application in a similar manner to straw yield.

An analysis of the yield of grain in terms of ear number, number of grains per ear and 1,000-corn weight gave results which varied greatly from year to year. The widely held view that early applications of nitrogen increase the yield of grain by increasing the number of ears, while late applications mainly affect ear size, was not confirmed in the field experiments, though it has previously been found to be true for pot cultures.

The effect of the nitrogenous fertiliser on the quality of the grain as measured by its nitrogen content and 1,000-corn weight also varied with the season. The 1,000-corn weight was usually depressed by the nitrogenous fertiliser whatever the time of application.

The nitrogenous fertiliser increased the susceptibility of the crop to lodging, and early top-dressings had a greater effect than late top-dressings.

The usual practice of applying the nitrogenous fertiliser as a top-dressing in February or March is justifiable on the grounds of convenience, and because applications of nitrogen at this time give as great an increase in the yield of grain as later spring top-dressings, and a greater increase of straw yield. But in circumstances where a high yield of straw is not particularly desirable, it would be advantageous to delay the top-dressing until May, and so to minimise the risk of lodging. Applications at the time of sowing appear to have no special advantage.

TECHNICAL PAPERS

6. DE ROPP, R. S. 1945. *Studies in the physiology of leaf growth. I. The effects of various accessory growth factors on the growth of the first leaf of isolated stem tips of rye.* Ann. Bot., **9**, 369-81.

Excised stem tips of rye were grown in sterile culture in darkness. It was found that on a medium containing 2 per cent. sucrose and mineral salts, growth was confined to the first leaf. The growth of this leaf was less than in excised whole embryos or in intact grains. In the absence of mineral salts growth was much reduced, and when sucrose was withheld no growth occurred. Occasionally, for reasons not yet understood, some of the stem-tips regenerated roots and when this happened, the entire growing point began to develop, and produced leaves normal in size and form.

Extracts of rye-grain, sprouted or unsprouted, of rye endosperm or of dried yeast added to the culture medium had no effect on the growth of the first leaf. American workers have claimed that a diffusate obtained from peas increases the growth of immature leaves grown in synthetic media, but this was not confirmed.

The following vitamins and other substances which have, or are claimed to have, effects on the growth of plant tissues, were also tested : thiamin, nicotinic acid, calcium pantothenate, pyridoxine, biotin, ascorbic acid, vitamins E and K, indole acetic and naphthalene acetic acids, and the purine derivatives, adenine, guanine, uric acid and caffein. None of these increased the growth of the first leaf in stem-tip cultures, but some had inhibiting effects at the higher concentrations tested.

7. Anon. 1941. *Contamination of crops by war gases : effects and treatment.* Min. Agric. Fish., Tech. Commun., **4**.

A short account is given of the different types of war gases and of the methods available for their dispersal. The effects of these gases on agricultural crops are discussed. The most probable method of contamination, and the one likely to have most serious effects, was considered to be by the persistent vesicant gases, mustard gas and lewisite, sprayed from aircraft. A detailed description is given in tabular form of the immediate visible effects of contamination with mustard gas or lewisite on common agricultural crops at different stages of growth, and of the effect on subsequent growth and yield.

It is pointed out that toxicity arising from contamination with mustard gas is rapidly removed by weathering, but crops contaminated with lewisite may continue to be poisonous for long periods of time. The conditions of contamination with lewisite which would render a crop unsafe for use as food are noted.

The procedure to be followed in handling and disposing of contaminated crops is described.

8. Watson, D. J. and Williams, C. 1943. *The salvage and decontamination of barley contaminated with persistent war gases.* J. Inst. Brewing, **49**, 303-6.

9. Watson, D. J. and Williams, C. 1944. *The salvage and decontamination of malt contaminated with persistent war gases.* J. Inst. Brewing, **50**, 292-4.

These two papers discuss the probable effects of a gas-bomb bursting in a stored bulk of barley or malt, and suggest a procedure to be followed in salvaging and disposing of the contaminated grain. It is shown that contamination is likely to be restricted to a very thin surface layer of the bulk of grain. If this is removed by careful shovelling, the underlying grain can be recovered uncontaminated. If the contaminant is mustard gas, the heavily contaminated grain in the surface layer can be decontaminated by heat treatment in a malting kiln, in conditions determined by experiments which are described, followed by a period of storage with good ventilation. After this treatment the grain is no longer toxic and the ability of barley to germinate is restored. Grain heavily contaminated with lewisite cannot be decontaminated by this method, and should be destroyed.

DEPARTMENT OF STATISTICS

By F. Yates

The Statistical Department was originally founded in order to carry out analyses of the accumulated results of the classical experiments at Rothamsted, and to provide statistical assistance for other departments of the Station, but it soon became apparent that considerable researches into statistical theory and method were also required. The results of these researches into theory and method are naturally of interest to research workers in many fields, and the Department has been continuously consulted by outside bodies on the statistical methods appropriate to the analysis of widely varying problems.

The statistical methods developed for handling biological material were found to be specially suitable for dealing with the statistical problems arising in the conduct of military operations, since the observational data relevant to such problems are characterised by a high degree of variability and are in many other ways similar to the data obtained in the course of biological experiment and observation. The accepted statistical measure of the effectiveness of different types of bomb, for example, and of alternative forms of protection against different types of bomb was evolved by the Department a year before war broke out.

It was a natural consequence, therefore, that during the war a great deal of the time of the Department should be devoted to the study of problems not directly connected with the work of Rothamsted. Much of this work arose in connection with urgent war problems, and insofar as many of these problems were of an ephemeral nature, this has interfered with more fundamental and long-term research. On the other hand, contact with widely differing types of problem and different types of material has been fruitful in introducing new methods which are likely to be of value in agricultural research. The need for a closer link between the technical and economic aspects of developmental research has also become apparent, and insofar as the relevant problems are in general quantitative and statistical, they should be the concern of the statistical departments of the research stations.

In addition to work directly connected with investigations of other departments of Rothamsted, and work undertaken for other agricultural institutions, and for the Ministry of Agriculture, the Department in the earlier part of the war carried out work for the Forestry Commission, the Timber Control (Ministry of Supply), and the Home Grown Timber Production Department (Ministry of Supply). This work was mainly concerned with the assessment of timber supplies, and the Department was actively associated both with the 1938-39 and 1941 Censuses of Woodlands. During a great part of the war, Dr. Yates was involved in operational-research problems, first for the Ministry of Home Security and then for the Air Ministry. These investigations were concerned both with protection against air attacks on this country and with the assessment of the effects and planning of air attacks on the enemy. In the course of this work Dr. Yates spent three months in Sicily in the autumn and winter of 1943 and also several months in France,

Belgium and Germany in 1944-45. Other members of the Department, particularly Mr. Kempthorne, have also assisted in statistical problems arising in operational research.

The only members of the staff who have remained with the Department during the whole of the period have been Dr. F. Yates, Dr. D. A. Boyd, Mr. J. W. Weil, and Miss P. Hurt (now Mrs. Morwood), Secretary. Mr. W. G. Cochran left to take up a post of Assistant Professor in Statistics at Iowa State College, Ames, Iowa, in August, 1939. He was succeeded by Mr. D. J. Finney, who has recently been appointed as Lecturer in the Design and Analysis of Scientific Experiment in the University of Oxford; Mr. Finney left to take up this post in September, 1945. Dr. Boyd, who had worked in the Department for two years (1937-39) as a post-graduate research worker, was appointed to the staff of the Department in October, 1939. Mr. O. Kempthorne joined the Department in July, 1941 from the Ministry of Supply. Mr. M. H. Quenouille was appointed in September, 1944. Mr. F. J. Anscombe and Mr. A. E. Jones joined the Department in November, 1945, Mr. Anscombe from S.R.17, Ministry of Supply and Mr. Jones from Armament Research Department, Ministry of Supply. Mrs. I. Mathison took up an appointment as Supervisor of the Survey of Fertiliser Practice in July, 1941.

The history of the war years would be incomplete without mention of the fact that at the outbreak of war the Galton Laboratory was evacuated to Rothamsted and remained here during the whole course of the war, thus continuing the long association between Professor R. A. Fisher and the Department. Mrs. R. O. Cashen, after doing two years' research work on the effects of rainfall on the permanent grass plots at Rothamsted under Professor Fisher, joined the Department when Professor Fisher left to become the Arthur Balfour Professor of Genetics at Cambridge.

In addition to the above workers there have been a number of workers who have been with the Department for shorter periods during the war. Miss R. Sumpton supervised the computation of the analysis of the National Farm Survey for two years from July, 1943 to August, 1945. Dr. E. C. R. Reeve carried out work on the 1938-39 Census of Woodlands and for the Ministry of Home Security, being with the Department from August, 1940 to December, 1940. Mr. J. S. Gregory took up a temporary post from August, 1943 to September, 1944. Mr. W. L. Stevens transferred from the Galton Laboratory in March, 1941 before taking up a post as Lecturer in Statistics at Coinbra, Portugal, on behalf of the British Council. He is now research statistician to I.C.I. Billingham.

The following voluntary workers and students have worked in the Department during the period 1939-45.

Name	*Location*	*Period of Visit*
R. N. P. Luddington	The United Africa Co., Ltd., West Africa	Aug. 1938–Jan. 1939
Helen N. Turner	Counc. for Sci. & Ind. Res., Australia	Jan. 1939–Aug. 1939
P. A. Loiziedes	Dept. of Agriculture, Greece	April 1939–Aug. 1939
P. N. Sahni	Agric. College, Punjab, India	April 1939–Sept. 1939
G. Polychroniades	Inst. for Plant Breeding, Greece	July 1939
D. E. V. Koch	Dept. of Agriculture, Ceylon	July 1939–Aug. 1939
L. Lebacq	Unilever Ltd., Belgian Congo	July 1939–Aug. 1939
A. F. MacKenzie	Dept. of Agriculture, Sierra Leone	July 1939–Aug. 1939

Name	*Location*	*Period of Visit*
S. H. Justesen	Afric. Exper. Station, Java	Aug. 1939
P. P. Agarwal	Lucknow, India	Aug. 1939–Sept. 1939
E. J. Williams	Counc. for Sci. & Ind. Res., Australia	Sept. 1939–Mar. 1940
V. G. Panse	Instit. Plant Industry, Central India	Sept. 1939–April 1940
F. Ferguson	United Africa Company, Nigeria	Oct. 1939–Dec. 1939
M. A. Kleczkowski	Poland	Oct. 1939–Mar. 1940
J. Reynolds	England	Oct. 1939–April 1940
A. Sismandis	Dept. of Agron., Tobacco Inst., Greece	Nov. 1939–Dec. 1939
R. A. Aguirre	Nitrate Corporation, Chili	Nov. 1939–Jan. 1940
A. G. Riaz	Agric. Dept., Punjab, India	May 1940–June 1940
B. Lessware	Assam Frontier and Budla Betta Tea Co., Assam	Sept. 1940
T. M. Carey	Cork University, Ireland	Jan. 1943–June 1945
S. Michaelson	Imperial College of Science, London	July 1944–Sept. 1944
M. Bernal	Imperial College of Science, London	July 1944–Sept. 1944
B. Monic	Poland	Sept. 1944–Oct. 1944
T. Chinloy	Dept. of Sci. and Agric., Jamaica	Jan. 1945–Jan. 1946
F. W. Cope	Dept. of Agriculture, Grenada	June 1945–July 1945
M. A. G. Hanschel	Agricultural Dept., Sierra Leone	July 1945–Aug. 1945
C. E. Ford	Rubber Research Scheme, Ceylon	Nov. 1945–Dec. 1945

Work of the Department

The work of the Department can be broadly classified under five heads :

(1) Researches in statistical theory and method.
(2) The planning of experiments and experimental programmes.
(3) Routine statistical analyses of the results of experiments, etc.
(4) Critical statistical analyses of bodies of experimental and observational data.
(5) The planning and analysis of sampling and other surveys.

Individual pieces of research may involve work under more than one of these heads. Thus, work under any one of the last four heads may give rise to problems which require research in statistical theory and method. Equally, an experimental programme may involve work at the planning stage, at the routine analysis stage, and also in the final critical examination of the results. In the subsequent sections of this report researches in statistical theory and method have been grouped together, as has work on surveys, while the various investigations which have required work under one or more of heads 2, 3 and 4 have been grouped under " Special Investigations."

Practically all work under the last four heads is carried out in conjunction with other departments of Rothamsted and with other research institutes. One of the most useful and interesting of the activities of the Department has lain in the preliminary discussions on experimental projects. Research workers inexperienced in the possibilities of modern experimental design frequently fail to realise the advantages which accrue from planning field investigations in a comprehensive manner. Projects are consequently over-simplified, often from a mistaken desire to obtain high accuracy on one particular point, with failure to recognise that this accuracy is of no value if the particular set of conditions postulated by the experimenter does not happen to hold. Planning of experimental programmes demands not only choice of suitable experimental designs, and possibly research into the theory of experimental

design, but also a careful choice of the factors and combinations of factors to be included in the experiments.

The Department carries out each year a considerable number of routine statistical analyses of the results of replicated experiments, including almost all the field experiments of Rothamsted and its associated centres, and a number of the laboratory and other experiments of the Station. In addition other institutes, both in this country and overseas, from time to time send us the results of experiments which they have found difficulty in analysing themselves : although only general advice is usually asked for, it is more satisfactory, and often quicker, if a worker is in difficulty in the statistical analysis of some experiment, to base such advice on the results of a full analysis. The Department is also frequently asked to advise on sampling methods, and this involves routine calculation in the estimation of sampling errors of new types of material. All this work follows a fairly standard pattern and need not be further discussed in the present report.

Researches in Statistical Theory and Method

As mentioned in the introductory section this aspect of the work of the Department has necessarily been somewhat neglected during the war, and the methods that have been evolved have in the main been developments of already well known principles, designed to deal with the increasingly complex situations to which these principles are being applied. The general principles of statistical analysis evolved in the inter-war period are applicable to a very wide variety of problems, and quite apart from the war, the trend of the work of the Department is likely to lie more and more in the direction of development of new applications of already established principles. Each problem requires its own specialised approach, and one of the troubles in the past has been over-generalised treatment which has taken insufficient account of the many complexities to which each problem is subject.

General

A certain amount of research has been carried out on miscellaneous mathematical statistical problems. Accounts of problems arising in operational research have not yet been published. Published papers on other problems are : (3), which gives an exact test of significance for the largest apparent effect in a replicated experiment containing several factors ; (4), which discusses the problem of estimating the mean and variance and of making tests of significance on statistics arising from very skew distributions ; (5) and (6), which discuss some orthogonal properties of the 4×4, 5×5 and 6×6 Latin squares, which are of value in experimental design ; and (7) which discusses the problem of estimating the error of a ratio.

A table for the estimation of densities of organisms by the dilution method has been calculated by Mr. W. L. Stevens, and was incorporated in the second edition of *Statistical Tables* (1).

An elementary account of the principles of biological statistics will be found in (8).

DESIGN OF EXPERIMENTS

The design of short-term agricultural field experiments had been fairly thoroughly developed before the war. The summary *The Design and Analysis of Factorial Experiments* (F. Yates), published in 1937 by the Imperial Bureau of Soil Science, made available a repertoire of methods adequate for dealing with most problems arising in short-term experiments. During the war years steadily increasing use has been made of these methods. It is now generally recognised—what was by no means the case before the war—that the modern type of factorial design results in more efficient use of experimental resources, and that by permitting the simultaneous investigation of a number of related factors, it enables an understanding of the underlying phenomena to be obtained that was impossible with the old simple type of experiment. Thus, the experiments on organic manures conducted during the last few years by the Chemistry Department, which were designed to give information on the responses to the three main inorganic fertiliser components (N, P, K) in the presence and in the absence of organics, have resulted in a much better understanding of the action of organic fertilisers, since they have permitted the separation of the effects which are attributable to the nutrient components in these fertilisers.

The chief developments of method applicable to short-term experiments have been refinements of techniques of which the principles were already known. Researches on the recovery of inter-block information in incomplete-block designs and lattice squares were completed shortly after the outbreak of the war, and accounts have been published (9, 10). Methods applicable to two-dimensional lattices have been described in a publication of Iowa State College, " The Analysis of Lattice and Triple Lattice Experiments in Corn Varietal Tests. I. Construction and Numerical Analysis. II. Mathematical Theory," by G. M. Cox, R. C. Eckhart and W. G. Cochran. Although originally planned for variety trials involving a large number of varieties, lattice squares have proved very suitable for trials of different types of organic fertilisers, having the advantage over ordinary confounded designs that equal precision is obtained on all comparisons. More recent developments have been the use of half-replicate designs (11), and confounding of sub-plot treatments (12, 13). The latter procedure has proved of great value in the organic-fertiliser trials mentioned above; each main plot, for example, can be split into four sub-plots, which receive either the treatments *n*, *p*, *k*, *npk*, or the treatments *nil*, *np*, *nk*, *pk*, the three-factor interaction NPK being thus confounded with main plots.

A certain amount of research has been carried out on the design of long-term experiments, e.g., experiments for assessing the residual and cumulative values of manures, the effects of different crop rotations, etc. Most of these researches have been of an *ad hoc* nature to provide designs for specific experiments: a considerable number have been for experiments in the tropics. General systematisation of designs of long-term experiments, corresponding to that already carried out for short-term experiments, still remains to be undertaken, and is one of the most urgent tasks in the field of experimental design.

The new methods are also capable of being applied, much more widely than they have been in the past, to experiments involving animals, particularly experiments on animal husbandry and animal nutrition, and research is required into these applications.

The new methods of experimental design are now beginning to be widely used in the industrial field, in order to test out modifications in manufacturing processes, etc. While experiments of this nature do not normally come within the province of the Department, it is inevitable that members of the Department should occasionally be consulted on such problems: designs have been worked out from time to time for dealing with very different types of material from those normally met with in agricultural field experiments.

On the analysis side, a method of utilising Hollerith machines for the analysis of factorial experiments of the 2^n type has been evolved (14), and has been successfully applied in the analysis of the 1944 and 1945 Factory Series of Sugar Beet Fertiliser Trials. This method is of particular value to the Department as it smooths out the peak load on the computing staff.

Genetics

In continuation of work carried out when working under Professor R. A. Fisher at the Galton Laboratory, Mr. Finney conducted a series of researches into the mathematical problems of estimation arising in the detection of linkage in human populations, which are characterised by the fact that information is often fragmentary, covers one or two generations only, and is always observational rather than experimental. Several papers have been published on the subject (15-21).

While with the Department, Mr. W. L. Stevens published a note giving exact fiducial limits of expectations, based on small numbers of observations derived from the binomial and Poisson distributions (22). These are applicable to the determination of the accuracy of mutation rates (for which the ordinary standard-error formula is grossly misleading), and to many other analogous problems. An extended set of tables was prepared by him for inclusion in the Second Edition of *Statistical Tables* (1).

Dr. Yates read a paper to the Seventh International Genetical Congress, held in Edinburgh immediately prior to the war, on modern experimental design and its function in plant selection (23).

Biological assay

The foundation of the rigorous statistical treatment of data arising in biological assay and toxicology was laid by Professor Fisher in 1935, in an Appendix to a paper by C. I. Bliss, who was then working at the Galton Laboratory. Since then the Department, in co-operation with the Insecticides Department, has played a very active part in developing statistical methods suitable for use in this field.

The most important problems investigated during the period under review have been the interpretation of toxicity tests of mixtures of poisons (24), the extension of the principles of factorial design to toxicological experiments, (25, 26), and the development

of methods for allowing for mortality amongst the controls (27). Mr. Finney has completed a text book on the subject (2), and tables suitable for use in laboratories have been included in *Statistical Tables* (1); a table dealing with tests in which there is mortality amongst the controls has been added to the third edition. Other papers published on the subject are (3), (28), (29) and (30).

Sampling

Prior to the war the Department was chiefly concerned with sampling problems arising in agricultural and biological research, such as sampling of agricultural crops for estimation of rate of growth, changes in chemical composition, yield, disease infestation, etc. The estimation of the yield of cereal experiments by sampling for the ratio of grain to total produce is discussed in (32). Since the war, the Department has been involved in many other types of sampling problems and the opportunity has been taken to make a thorough review of the whole of the theory of sampling. A review of the present position has been given in a paper read to the Royal Statistical Society in January, 1946 (31). Dr. Yates is also preparing a book on the subject.

Sampling problems arising in economic surveys and in the analysis of economic material have also been investigated in connection with the Survey of Fertiliser Practice (page 264), and the analysis of the National Farm Survey (page 117). The technique of dealing with sampling errors in large-scale surveys of disease and pest infestation have been worked out in connection with the Wireworm Survey (page 116). The sampling problems arising in this survey are discussed in (50). Sampling problems connected with social surveys entered into a number of the investigations conducted by the Ministry of Home Security.

The problem of estimating the sampling error of systematically spaced samples, such as are often used in forestry surveys, is being investigated. While this investigation is not yet complete, considerable advances have been made, and it is likely to be brought to a successful conclusion during the present year.

Special Investigations

The war gave rise to urgent demands for accurate information on many diverse problems. Such information was required as a basis for immediate administrative action, and when the demand arose, there was usually no time for experimental work, so that it was imperative to make use of whatever material was available.

During the war the Department undertook a number of summaries of experimental material relevant to particular problems. The first of these was the summary of the results of all the fertiliser trials conducted in this country since 1900 which is described elsewhere in this report (page 263).

This investigation revealed two points of general importance in research policy. The first was the value of making critical quantitative reviews from time to time of the whole of the available experimental data on given problems. Such quantitative reviews were found in general to require critical statistical re-examination and synthesis of the relevant results. Previously statistical examinations

carried out in the Department had been confined (apart from those of modern co-ordinated series of experiments) to the results of particular experiments, such as the classical fields at Rothamsted. In these examinations the results of each experiment had been considered alone without reference to similar experiments elsewhere. It now became clear that consideration of all available experimental results throwing light on some particular problem was often much more profitable, the results of past experiments being used as a quarry to provide information on different points as required.

The second point that emerged was that the summarisation of large bodies of experimental work carried out by many workers, often in different countries, requires time for its efficient execution, quite apart from the fact that the summary, when complete, may result in the conclusion that further experimental work is necessary. Administrators, working usually under urgent pressure of day-to-day demands, cannot be expected to become aware sufficiently early of technical and scientific points on which information will be required in the future. Consequently scientists themselves, particularly in times of rapid change, must co-operate with the administration in determining what problems are likely to become of importance in the future, so that the necessary investigations can be initiated in good time.

Effect of changes in level of feeding of dairy cows on milk production

At the request of the Agricultural Economics Branch of the Cambridge School of Agriculture, the Department co-operated with the Economics Branch in an investigation of the effect of changes in level of feeding of dairy cows on milk production. The questions that gave rise to the investigation were how far feeding stuffs could be economised by stricter rationing of dairy cows, and how far concentrates could be replaced by bulky foods.

In order to determine the most efficient feeding policy, the relationship between food intake and milk output must be known. It was originally hoped that the data collected by the Cambridge Economics Branch on the food consumption and milk outputs of a sample of dairy herds in the eastern counties would be adequate, but it was eventually concluded that the data were not by themselves capable of furnishing certain information on this point. It was therefore decided to review all relevant feeding experiments and make a comprehensive analysis and summary of the results. This investigation is reported in (33). It is well known that as the food intake increases the digestive efficiency of an animal falls off. On the other hand, every animal has a high overhead requirement, which in a dairy cow includes not only the maintenance ration, but also food required during dry periods and food for rearing, etc. This would indicate that it may be advantageous to keep cows at a high productive level, even though this may lead to some digestive inefficiency. The analysis showed that a level of feeding slightly higher than the normal rations given in " Rations for Livestock," gave maximum efficiency in terms of milk production and that while raising the feeding above this level was not likely to result in any great loss of efficiency, feeding rates lower than those given in " Rations for Livestock," resulted in a rapid fall in milk production,

and a corresponding loss in efficiency. It thus appeared that economies of food were not likely to be effected by more stringent rationing of dairy cows, except at the expense of milk yields. Over-stringent rationing resulting from shortage of foods might result in a very serious reduction in the milk supply without any equivalent saving in food.

Evidence on the part played by bulky foods was also obtained, and it was shown that, provided total energy intake was maintained, substitution of part of the concentrates normally fed to a dairy cow by bulky foods, such as roots or hay on an equal starch-equivalent basis did not influence milk yield. It was also found that in the experiments investigated the starch-equivalent system gave better assessment of the relative energy values of different types of food than did the Danish food-unit (F.E.) system, or the total digestible nutrients (T.D.N.) system.

Changes in level of feeding result not only in changes in milk production, but also in changes in live-weight. These changes complicated the interpretation of the results, particularly of the short-term experiments. Some of the experiments also threw light on protein requirements for milk production. These results, however, have not been fully summarised.

Assessment of the value of ley farming

A start has been made in 1945 on planning an investigation of the economic value to the livestock farmer of temporary grazing leys as compared with old grass. A committee, the Joint Supervisory Committee on Ley Farming, was set up by the Ministry towards the end of 1944, to consider possible ways of securing this information. When the problem was reviewed it was decided that before starting direct experimental work it was essential to ascertain whether any satisfactory technique, other than measurements of liveweight increases and grazing days, could be evolved for assessing the yields of grazed pastures, since the use of animals necessarily involves large plots, and consequently the experiments have to be of a very simple nature, and even so only attain very low accuracy.

The cutting of grass at frequent intervals on small caged plots has been tried out in various parts of the world, but a review of the literature showed that the alternative techniques had not been adequately tested. In view of this, trials to compare various cutting techniques with the performance of the animals themselves were instituted by the Ministry and the Grassland Improvement Station in 1945. One of these was carried out at Rothamsted on the Royal Agricultural Society's trial of the residual value of cake feeding (page 236). The grass-cutting work on this trial was carried out by members of the Statistical and Chemistry Departments, and the statistical analysis of all the trials was performed at Rothamsted. The results of the 1945 trials are promising, and the work is being continued in 1946.

This investigation forms only a small part of the more general problem which may be broadly described as the determination of the agronomic and economic value of ley farming relative to other farming systems. The problem is exceedingly complex, involving agronomic research into methods of establishing leys, the evolution

of suitable strains of grasses and clovers for varied climatic conditions and grazing requirements, the determination of the fertiliser requirements of a ley-arable rotation, etc., and such general questions as the relative merits of leys and permanent grass for pasture and for hay, and the increase in fertility of arable land attributable to leys. It is naturally the concern of many other research institutes as well as Rothamsted. Until a quantitative answer is obtained to these general questions an economic assessment of the relative value of ley and other systems of farming under any given economic conditions cannot be made.

Investigations on fertility questions are necessarily both involved and slow. Consequently, in spite of their recognised importance, little work has been done during the war, for it was apparent that no information could be obtained which would be of value in increasing agricultural production during the war. Prior to the war the only experiment in this country designed to assess the influence on fertility of the introduction of long leys into arable farming was the Woburn experiment described elsewhere in the report (p. 256). This experiment illustrates the lengthy nature of all such investigations : although started in 1938, the first cycle will only be complete in 1946. The fact that the war has interrupted the laying down of similar experiments at other centres makes the present need all the more urgent. They should have high priority in the programmes of the new experimental farms to be established under the National Advisory Services.

Other investigations

Dr. Boyd carried out a statistical examination of 36 years' results of the Saxmundham Rotation Experiment, studying both the responses to fertilisers and the influence of meteorological factors (40). Mrs. Cashen (Mrs. Tysser), working under Professor Fisher, investigated the effect of rainfall on the yields and botanical composition of hay from the Park Grass Plots at Rothamsted (41). Dr. Carey made an investigation of the fertiliser requirements of sugar cane, including a summary of the results of all available fertiliser experiments on this crop (42). All three workers were awarded a Ph.D. at London University.

The accounts of various small investigations which have been carried out during the last seven years are described in the abstracts to papers (34)-(39) and (43)-(47). Certain other investigations have been made of which the results are not yet published.

Trials to assess the value of the resazurin and methylene-blue tests as measures of the keeping quality of milk were instituted in 1944 by the Ministry acting in conjunction with the Conference of Advisory Bacteriologists. The planning and statistical analysis of these trials have been supervised by this Department. The statistical work has been carried out partly at Hove, and partly at Rothamsted. The Department has co-operated in preparing two reports on the results of the trials.

Surveys

During the war the importance of obtaining accurate and reliable information on farming conditions, and on the actual agricultural

practices of different types of farmers was increasingly realised. Such information is of importance both to the administration in planning the utilisation of scarce resources, development of rationing schemes, etc., and to those engaged in the planning of research and in the dissemination of established scientific and technical knowledge. The subject is fully discussed in (48).

Information of this type can often only be obtained by special surveys of agricultural conditions and practices. The Department has been increasingly consulted on the planning and analysis of such surveys, particularly in connection with the sampling problems that arise in surveys covering only a sample of all farms or fields, or which involve the sampling of individual fields. On the subject of crop estimation and forecasting, on which a good deal of work had been carried out before the war, advice and assistance was given from time to time to the Ministries concerned with wartime estimation problems. The sampling observations on the growth of wheat conducted in the years 1933-1939 at several centres under the Agricultural Meteorological Scheme of the Ministry were abandoned owing to pressure of more urgent war work, but certain tests on the feasibility of using eye estimation for estimating the yields of cereal crops were carried out on the wheat crop in Hertfordshire in the years 1940 and 1941. Mention of this work will be found in (48).

In addition to advisory work the Department has been more closely concerned with three major pieces of survey work; the Survey of Fertiliser Practice, described elsewhere in the report (page 264), the Wireworm Survey, and the National Farm Survey.

The wireworm survey

This survey was instituted because of the importance of the wireworm problem under war conditions, when large amounts of old grass were turned over to arable cropping. Its primary object was to evolve methods suitable for assessing wireworm infestation of particular fields, so that advice could be given to farmers on cropping, preventive measures, etc. The material collected also provided a good deal of general information on the wireworm problem.

The survey work was carried out by the Advisory Entomologists acting under the direction of the Plant Pathological Laboratory of the Ministry. The Department gave statistical advice to the Plant Pathological Laboratory on the conduct of the survey, and Mr. Finney played a large part in the drafting of the various reports.

On the statistical side, the survey involved a good deal of preliminary work in the investigation of the errors involved in the sampling of individual fields, and in the evolution of the most suitable methods of sampling. This aspect is discussed in (49) and (50).

In addition, the whole of the statistical side of the reduction and examination of the results was for several years concentrated at Rothamsted, and this involved a very considerable amount of numerical work.

The results of the survey have been reported in a Ministry of Agriculture Bulletin (52).

National farm survey

During the year 1941-42, the Ministry, acting through the County War Executive Committees, carried out a qualitative survey of all farms of over five acres in England and Wales. The aims and objects of the survey were reported in the Press at the time. The survey covered such aspects as tenure, condition of farm, incidence of insect pests, quality of farming, supply of electricity and water, etc., and included a map record of all farm boundaries. Owing to the labour situation, the analysis on a national basis of the results of this survey by the Ministry's Statistical Department presented serious difficulties, and the Ministry therefore made use of the assistance of Rothamsted. The analysis was carried out by means of Hollerith punched-card equipment, and the numerical work at Rothamsted consisted of summarising the tables produced by the tabulating machines. This work was of a routine character, and a special team of part-time computers was used.

The survey has given the Department valuable experience in the use of Hollerith machinery on the analysis of this type of material, and as a result methods of utilising this machinery have been considerably developed. The data of the survey and of the related June 4th Returns also presented points of general interest on which further investigations have been carried out.

A full report on the survey has been published by the Ministry, (*The National Farm Survey, a Summary Report*, Ministry of Agriculture, H.M.S.O., 1946).

PUBLICATIONS

BOOKS

1. Fisher, R. A. and Yates, F. 1946. *Statistical Tables for Biological Agricultural and Medical Research. 1st Edition*, 1938 ; *2nd Edition*, 1943 ; *3rd Edition*, 1946. Oliver and Boyd, Edinburgh. (In the press.)

These tables have been designed to give a collection under one cover of all those tables that are normally required by the agricultural and biological statistician. In addition to the tables already published in *Statistical Methods for Research Workers* and elsewhere, various new tables have been specially computed for the volume by members of the Statistical Department and of the Galton Laboratory. Opportunity has been taken to add additional material in each new edition.

2. Finney, D. J. 1946. *Probit Analysis. A Statistical Treatment of the Sigmoid Response Curve.* Cambridge University Press. (In the press.)

This is a practical working text book designed to give the biological statistician, previously unfamiliar with the subject of probit analysis, a complete account of the subject, including the most recent developments

1. RESEARCHES IN THEORY AND METHOD

(*a*) *General*

3. Finney, D. J. 1941. *The joint distribution of variance ratios based on a common error mean square.* Ann. Eug., **7**, 136-140.

The paper gives the probability distribution of the ratio of the largest of a number of mean squares, all based on the same number of degrees of freedom, to an independent " error " mean square. The computation of exact significance levels is a lengthy process, but the approximation resulting from an assumption of complete independence of the ratios is satisfactory providing that the error degrees of freedom are sufficiently numerous. The determination of significance levels for the least of the variance ratios is arithmetically much simpler, and the similar approximation very satisfactory.

4 FINNEY, D. J. 1941 *On the distribution of a variate whose logarithm is normally distributed.* Suppl. J. Roy. Stat. Soc., **7**, 155-161.

Formulae have been obtained for efficient estimates of the mean and variance of a sample of a population of which the logarithm of the variate is normally distributed. As the exact expressions are not very suitable for arithmetical computation, approximations are developed which may be used for moderately large samples.

5. FINNEY, D. J. 1945. *Some orthogonal properties of the* 4 *by* 4 *and* 6 *by* 6 *Latin squares.* Ann. Eug., **12**, 213-219.

Though there are no 6 by 6 Graeco-Latin squares, it is possible to partition 6 by 6 Latin squares orthogonally but less completely. The paper discusses these partitions and gives examples for use in experimental design. The existence of partitions satisfying various more stringent conditions is noted.

All 4 by 4 Latin squares can be partitioned, in six different ways, into two sets of eight cells satisfying similar conditions, though only one-quarter of these squares have Graeco-Latin solutions ; these partitions also are tabulated.

6. FINNEY, D. J. 1946. *5 by 5 Latin squares.* Ann. Eug. **13**, 1-3.

All orthogonal partitions of the 5 by 5 Latin squares have been determined, and the implications of the results in experimental design are discussed.

7. COCHRAN, W. G. 1940. *The validity of an approximate formula for the variance of a ratio.* (Appendix.) J. Agric. Sci., **30**, 273-275.

The validity of the usual approximate formula for calculating the variance of a ratio is briefly discussed.

7A. KEMPTHORNE, O. 1944. *Comments on the note "On a theorem concerning sampling."* J. Roy. Stat. Soc., **107**, 58.

8. KEMPTHORNE, O. 1945. *Statistics in biology.* Biol. and Human Affairs, **10**, No. 3, 1-8.

(*b*) *Experimental design and analysis*

9. YATES, F. 1940. *Lattice squares.* J. Agri. Sci., **30**, 672-687.

The paper describes a new method of analysing the results of experiments arranged in lattice (quasi-Latin) square designs, utilising the information contained in the inter-row and inter-column comparisons. The methods of computation are described in detail, and are illustrated by examples. With this modification, lattice squares will always give results which are as accurate as, or more accurate than, ordinary randomised blocks.

10. YATES, F. 1940. *The recovery of inter-block information in balanced incomplete block designs.* Ann. Eug., **10**, 317-325.

The method of recovering inter-block information in incomplete block designs is described and is illustrated by numerical examples.

11. FINNEY, D. J. 1945. *The fractional replication of factorial arrangements.* Ann. Eug., **12**, 291-301.

The relationship of schemes for factorial experiments to the elementary theory of prime power groups has been discussed with particular reference to 2^n and 3^n factorial arrangements. It is shown that fractional replication of these arrangements is permissible provided that the experimenter does not require information on high order interactions. A numerical example has been given for half-replication of a 2^n arrangement.

12. FINNEY, D. J. 1946. *Recent developments in the design of field experiments.* 1. *Split-plot confounding.* J. Agric. Sci., **36**, 56-62.

The design of experiments in which some of the interactions of the sub-plot treatments are confounded with the main plots is discussed.

13. FINNEY, D. J. 1946. *Recent developments in the design of field experiments.* 2. *Unbalanced split-plot confounding.* J. Agric. Sci., **36**, 63-68.

Further extensions of split-plot confounding to designs in which the number of variants of the different factors is such that complete balance is not possible, are described.

14. KEMPTHORNE, O. 1946. *The analysis of a series of experiments by the use of punched cards.* Suppl. J. Roy. Stat. Soc. (In the press.)

The analysis of the sugar beet series of fertiliser trials which are of 2^5 type of factorial design by means of Hollerith punched cards is described. Possible extensions to other types of experiment are briefly discussed.

(c) Genetics

15. FINNEY, D. J. 1940. *The detection of linkage.* Ann Eug., **10,** 171-214.

16. FINNEY, D. J. 1941. *The detection of linkage. 2. Further mating types : Scoring of Boyd's data.* Ann. Eug., **11,** 10-30.

17. FINNEY, D. J. 1941. *The detection of linkage. 3. Incomplete parental testing.* Ann. Eug., **11,** 115-135.

18. FINNEY, D. J. 1942. *The detection of linkage. 4. Lack of parental records and the use of empirical estimates of information.* J. Hered., **33,** No. 4.

19. FINNEY, D. J. 1942. *The detection of linkage. 5. Supplementary tables.* Ann. Eug., **11,** 224-232.

20. FINNEY, D. J. 1942. *The detection of linkage. 6. The loss of information from incompleteness of parental records.* Ann. Eug., **11,** 233-244.

21. FINNEY, D. J. 1943. *The detection of linkage. 7. Combination of data from matings of known and unknown phase.* Ann. Eug., **12,** 31-43.

In this series of papers methods are developed for making efficient tests of linkage from family records of the type usually encountered in human studies of genetics. These methods are based on scoring procedures of the type originally introduced by Professor R. A. Fisher.

22. STEVENS, W. L. 1942. *Accuracy of mutation rates.* J. Gen., **43,** 301-307.

The use of the standard error of estimates of mutation rates, and other small proprotions, is shown to be highly erroneous. A table is provided for rapidly making the exact tests of significance.

23. YATES, F. 1940. *Modern experimental design and its function in plant selection.* Emp. J. Exp. Agric., **8,** 223-230.

The paper gives a summary of the various experimental designs of the quasi-factorial, balanced incomplete block, and lattice square type, that have been introduced to test large numbers of varieties, while eliminating fertility differences as far as possible. The advantage of including a large number of varieties in field trials at the cost of some reduction in the accuracy of individual comparisons, in order to reduce the chance of some particularly good variety being rejected without trial, is stressed.

(d) Biological assay

24. FINNEY, D. J. 1942. *The analysis of toxicity tests on mixtures of poisons.* Ann. Appl. Biol., **29,** 82-94.

The interpretation of the results of toxicity tests on mixtures of poisons is fully discussed, new methods are developed for dealing with independent, similar and synergistic action, and examples of their application are given.

25. FINNEY, D. J. 1942. *Examples of the planning and interpretation of toxicity tests involving more than one factor.* Ann. Appl. Biol., **29,** 330-332.

The paper gives a brief review of toxicity tests which have included combinations of different techniques of applying poisons, or which have tested mixtures of poisons.

26. FINNEY, D. J. 1943. *The statistical treatment of toxicological data relating to more than one dosage factor.* Ann. Appl. Biol., **30,** 71-79.

The extension of factorial design to toxicological experiments involves new problems of analysis, which are discussed in this paper. It is shown that

probit regression planes can be fitted in a manner analogous to that used for regression lines. The arithmetical procedure of fitting is illustrated by an example and tests are given for heterogeneity and parallelism. Numerical examples used by Bliss are also discussed in relation to the methods of fitting and forms of equation given in this paper.

A more general class of equations is introduced for use when the probit mortality is linearly related to each dosage factor separately, but the individual effects are not additive.

27. FINNEY, D. J. 1944. *The application of the probit method to toxicity test data adjusted for mortality in the controls.* Ann. Appl. Biol., **31**, 68-74.

Methods of dealing with data in which the untreated controls are subject to a mortality rate are developed, and the necessary tables are presented.

28. FINNEY, D. J. 1944. *The application of probit analysis to the results of mental tests.* Psychometrika, **9**, 31-39.

The paper contains an outline of the method of probit analysis and an illustration of the most convenient form of computations for use in analyses of psychometric data.

29. FINNEY, D. J. 1944. *Mathematics of biological assay.* Nature, **153**, 284.

The applicability of the four-point assay is discussed.

30. FINNEY, D. J. 1945. *The microbiological assay of vitamins : the estimate and its precision.* Quart. J. Pharmac., **18**, 77-82.

The estimation of relative potency by the method of maximum likelihood is developed for the case, arising in certain micro-biological assays. in which the response shows a linear relationship with the dose and the regression lines for the two proportions are constrained to give the same value at zero dose.

(e) Sampling and sampling surveys

31. YATES, F. 1946. *A review of recent statistical developments in sampling and sampling surveys.* J. Roy. Stat. Soc., **109**, 12-30.

The paper gives a review of the present position of sampling theory and practice with an outline of the contributions made by biological and agricultural statistics. A summary of sampling methods and the appropriate methods of forming estimates and calculating sampling errors is given, including a discussion of methods of improving the accuracy by adjustment of the results. The use of ratios or percentages and the use of a variable sampling fraction including the problems arising in the estimation of error when quasi random or systematic sampling is used are also discussed. The sampling problems arising in social surveys and the planning of sampling enquiries, are reviewed.

32. COCHRAN, W. G. 1940. *The estimation of the yields of cereal experiments by sampling for the ratio of grain to total produce.* J. Agric. Sci., **30**, 262-275.

One possible method of determining the yields of cereal experiments is to weigh the total produce on each plot and to take samples for estimating the ratio of grain to total produce, either from the sheaves or from the standing crop. The paper discusses the sampling errors of this method, which is shown to require about $\frac{1}{2}$ of the number of samples that would be required in sampling directly from the standing crop. Grab sampling from the sheaves, though slightly biased, is otherwise satisfactory.

2. STATISTICAL ANALYSES OF COLLECTIONS OF EXPERIMENTAL AND OBSERVATIONAL DATA

33. YATES, F., BOYD, D. A. and PETTIT, G. H. N. 1942. *Influence of changes in level of feeding on milk production.* J. Agric. Sci., **32**, 428-456.

The influence upon milk production of changes in level of feeding and in proportion of bulky foods has been investigated using all available experimental material.

The experimental results show that increases in level of feeding, to rates well in excess of conventional English standards, are capable of giving substantial increases in milk production.

It is shown that physiological efficiency falls off as food intake is increased. A curve representing physiological efficiency has been constructed by taking account of changes in live weight as well as changes in yield of milk.

The question of the most efficient feeding rate is discussed. Owing to the high overhead and maintenance requirements of the cow, a fairly high level of feeding of about 2·8 lb. starch equivalent per gallon of milk, gives maximum efficiency. This is so in spite of lower physiological efficiency at high levels of feeding and additional loss resulting from the utilisation of part of the food supply to increase body weight. This feeding rate approximates to the rate which would have given maximum profit at 1941-2 prices if food could have been freely bought and sold. There is thus no economic inducement to feed at excessive rates, and the chief danger appears to be under-feeding, due either to too stringent rationing or to an attempt to keep too many animals in times of general food stringency.

The feeding of bulky foods alone may reduce yield owing to limitation of total energy intake. Provided total energy intake is maintained, substitution of part of the concentrate ration by bulky foods such as roots or hay, on an equal starch equivalent basis, does not influence milk yield.

The results of these experiments show that the starch equivalent system gives a better assessment of the relative energy values of different foods than does the food unit (F.E.) system or the total digestible nutrients (T.D.N.) system.

34. FINNEY, D. J. 1940. *The Little Hoos field experiment on the residual values of certain manures.* Emp. J. Exp. Agric., **8**, 111-125.

The paper contains an analysis of the results of the Little Hoos field experiment at Rothamsted (which ran from 1904-1926) on the residual values of various organic manures and forms of phosphate applied to a four-course rotation. The design of the experiment was such that no very definite conclusions could be drawn, but the experimental results appeared to show residual effects of dung up to three years from their application, but no residual effects for guano, shoddy or rape dust. Basic slag showed more consistent residual effects than superphosphate or bone meal.

35. TURNER, HELEN N. 1939. *The residual effects of organic fertilisers : A preliminary report on the Rothamsted four-course rotation experiment.* Emp. J. Exp. Agric., **7**, 343-349.

The paper gives a preliminary analysis of the first 8 years' results of the Rothamsted four-course rotation experiment on the residual effects of organic fertilisers.

36. GARNER, H. V. and WEIL, J. W. 1940. *The cultivation of malting barley in England.* Emp. J. Exp. Agric., **8**, 65-79.

The agricultural data and grading of some 1,200 samples of English malting barley are set out and discussed. Classification by differences showed marked differences in quality in different localities. Autumn sowing usually produced barley particularly superior in quality, but inferior in yield to the spring sown barleys. Samples sown early in the spring tended to be better in quality than those sown later in the season. The heavier class of soil tended to produce better barley in dry years and vice versa.

37. SAHNI, P. N. 1941. *The relation of drainage to rainfall and other meteorological factors.* J. Agric. Sci., **31**, 110-115.

Following the earlier work of CROWTHER and KOSHAL, the drainage from the Rothamsted 20 in. drain gauge has been related to rainfall and other meteorological factors.

38. FINNEY, D. J. 1941. *The relationship of plant number and yield in sugar beet and mangolds.* Emp. J. Exp. Agric., **9**, 57-64.

Examination of the relationship between plant density and yield in four widely different sets of experiments on sugar beet and mangolds indicates that, with a normal plant population, any elimination of roots may be expected to be accompanied by about half the proportionate loss in yield.

39. GARNER, H. V. and WEIL, J. W. 1939. *The standard errors of field plots at Rothamsted and outside centres.* Emp. J. Exp. Agric., **7**, 369-379.

The standard errors per plot obtained in some 1,200 analyses relating to data from modern replicated experiments carried out at Rothamsted, Woburn, and outside centres during 1925-38 are recorded and classified.

40. BOYD, D. A. 1940. *The influence of meteorological factors on arable crop yields, based on an examination of the results of the Saxmundham rotation experiment.* (Thesis for Ph.D. degree in the University of London.)

The results of this experiment from 1900 to 1937 are summarised and discussed, and the influence of meteorological factors is investigated.

41. CASHEN, R. O. 1944. *The effect of rainfall and associated weather on manurially treated permanent grassland as demonstrated by manurial experiments carried out since* 1856 *on the grass plots in Rothamsted Park.* (Thesis for Ph.D. degree in the University of London.)

The results of an examination of the effect of rainfall on the yields and chemical composition of the hay of the Park grass plots, Rothamsted, is reported.

42. CAREY, T. M. 1945. *Fertiliser requirements of sugar cane.* (Thesis for Ph.D. degree in the University of London.)

An investigation of the fertiliser requirements of sugar cane has been made, with a summary of all available fertiliser experiments on this crop.

See also: Department of Entomology, Refs. 21, 22, 30, 34; *Bee Department*, Refs. 14, 15; *War-time Fertiliser Policy*, Ref. 1.

3. SURVEYS

(*a*) *General*

48. YATES, F. 1943. *Methods and purposes of agricultural surveys.* J. Roy. Soc. Arts, No. 4641.

This paper gives a review of the current developments in agricultural surveys illustrated by examples of recently executed surveys.

(*b*) *Wireworm survey*

49. FINNEY, D. J. 1941. *Wireworm populations and their effect on crops.* Ann. Appl. Biol., **28**, 282-295.

The results of sample determinations of wireworm populations carried out by the Advisory Entomologists in connection with the Wireworm Survey in 1939-40 are reviewed. There was a very marked decrease in infestation from south to north of the country. The adequacy of the standard sampling technique employed (20 in. cylindrical cores 4 in. in diameter) is discussed, and the effects of wireworm infestation on the subsequent crops are analysed.

50. YATES, F. and FINNEY, D. J. 1942. *Statistical problems in field sampling for wireworms.* Ann. Appl. Biol., **29**, 156-167.

Grass fields have shown very much higher populations in the south-east and midland areas than in the north and west both in 1939-40 and 1940-41. In spite of a reduction in 1940-41 in the lower size limit of the larvae to be counted in the samples, populations in this latter season tended to be lower than in 1939-40. Arable fields sampled in 1940-41 gave populations generally lower than grass fields, and the geographical trend was less noticeable.

A general summary of the principles underlying field sampling, with particular reference to the taking of soil samples for the estimation of wireworm population, has been given.

51. FINNEY, D. J. 1943. *Recent developments in the wireworm survey.* Agric. Prog., **8**, 36-38.

Further results on the size of wireworm populations and damage to crops are briefly recorded.

52. 1944. *Wireworms and food production—a wireworm survey of England and Wales* (1939-1942). (Report from the Advisory Entomologists Conference.) Min. Agric. Bull., **128.**

This bulletin contains a full report of the results of the Wireworm Survey. Subjects discussed are : the technique of wireworm sampling, the distribution of *agriotes* populations in England and Wales, the influence of husbandry on wireworm populations, the influence of wireworms on the establishment and success of arable crops. Recommendations are made for mitigating damage due to wireworms.

(*c*) *Survey of fertiliser practice*

53. Yates, F., Boyd, D. A., and Mathison, I. *The manuring of farm crops : Some results of a survey of fertiliser practice in England.* Emp. J. Exp. Agric., **12,** 164-176.

The report presents some of the main findings of the survey which have immediate relevance from the point of view of improving the use of fertilisers. The report covers counties in the Advisory Provinces of Cambridge, Bristol and Leeds, and in the main relates to the manuring of the 1942 crops

Generally speaking, districts which have always depended mainly on arable cropping use adequate amounts of fertilisers, and make satisfactory differentiation between the needs of different crops. Even in these districts, however, the special needs of newly ploughed-out grassland have not been fully recognised, and crops tend to be manured without regard to the land on which they are grown.

Farmers in the dairy and cattle-rearing districts of the West of England and Yorkshire, who before the war had had little experience of arable farming, are much less " fertiliser-conscious " than farmers in the eastern arable counties, and make insufficient use of fertilisers, even on old arable land. For example, the manuring of root crops is frequently ill balanced and inadequate in the western counties ; although very large supplies of farmyard manure are available, almost one-third of the root acreage received none, and many fields received no phosphate or no nitrogen. Even within the chief arable districts there were many farms mainly in grass before the war (e.g., in West Bedford and South Essex), which make less effective use of fertilisers than their neighbours with greater experience of arable farming.

As a consequence, the use of lime and phosphate on new arable land has been quite inadequate over most of the surveyed area. The survey has confirmed (what has already been frequently emphasised) that new arable land is generally both much more acid and much more deficient in phosphate than old arable, but it is apparent that except in one or two districts this land has received less lime and less phosphate in recent years than has the old arable land.

The failure to recognise the function of farmyard manure as a source of phosphate, and more particularly potash, is also striking. The survey shows that farmers require encouragement to use mixtures with a lower proportion of phosphate and potash where farmyard manure is also given.

The failure to distinguish clearly between the different action of the various plant nutrients has also led to an inadequate use of nitrogen on cereals grown after roots, presumably owing to the belief that the heavy manuring of the roots will have led to sufficient stored-up fertility. Certainly in those cases where only inorganic nitrogen has been used to manure the root crop, there is every reason to give a reasonable nitrogenous dressing to the following corn. There are also wide differences from farm to farm in the use of nitrogen on cereals, and it is clear that some farmers, at least, could profitably make greater use of this fertiliser. Only half the acreage of cereals in the surveyed provinces actually received nitrogen, and it is unlikely that a higher proportion receives nitrogen in the country as a whole.

DEPARTMENT OF PLANT PATHOLOGY

By F. C. Bawden

Staff Changes

Dr. J. Henderson Smith retired from the post of Head of the Department on September 30th, 1940, and was succeeded by Mr. F. C. Bawden. The post of Virus Physiologist was then merged into that of Biochemist to the Station and filled by Mr. N. W. Pirie. In October, 1940 Dr. P. H. Gregory and Mr. J. P. Doncaster were appointed as Research Officers of the Agricultural Research Council and attached to the Department to study the factors affecting the spread of potato virus diseases in field crops. Mr. B. Kassanis, who entered the Department in October, 1938 with a research scholarship, was taken on the staff in March, 1941. Dr. A. Kleczkowski has worked in the Department since February, 1940, first with a grant from the Rockefeller Foundation and since 1942 as a Beit Memorial Research Fellow. From 1940 to 1943 Dr. F. M. Roberts worked on *Verticillium* wilt of tomatoes with a special grant from the Empire Cotton Growing Corporation and in 1943 was appointed to the staff for work on potato virus diseases. Dr. E. M. Crook came to the Station with a research grant from the Agricultural Research Council in 1942, and in 1944 was appointed to the staff of the Department to work on the electron microscope. Miss W. M. Ritchie (Mrs. Dion), who came in October, 1940 to replace Miss B. I. M. Mitchell for work on the insect transmission of virus diseases, later obtained a research fellowship to work on *Cercosporella herpotrichoides* from 1941 to 1943. Miss J. Smith was appointed in 1941 to assist with the work on the insect transmission of virus diseases. In 1942 Miss J. Moore was given a research grant by the Agricultural Research Council to study the factors responsible for wastage in stored potatoes and in October, 1944 was appointed to the Staff to work with Miss M. D. Glynne.

Others who have worked in the Department for periods of three months or longer are :—

Mr. W. Billet, Mr. I. D. Blair, Mr. S. P. Capoor, Mr. A. Christoff, Mr. J. J. Eshuis, Mrs. L. Kapica, Mr. B. Kvicala, Mr. P. Manil, Mr. T. S. Sadasivan, Mr. C. I. Shen, Miss J. Thurston, Miss E. M. Turner and Mr. A. G. Walker.

In 1939 Miss F. M. L. Sheffield was awarded the D.Sc. degree of London University and Miss M. D. Glynne the D.Sc. degree of the University of Wales in 1943. Ph.D. degrees of London University were obtained by Mr. I. D. Blair, Mr. S. P. Capoor, Mr. J. J. Eshuis, Mr. B. Kassanis, Dr. A. Kleczkowski, Miss B. I. M. Mitchell, Miss J. Moore, Miss W. M. Ritchie, Mr. T. S. Sadasivan, Mr. C. I. Shen, Miss E. M. Turner and Mr. A. G. Walker.

In addition to carrying out the research work summarised below, individual members of the staff have served on committees of the Agricultural Research Council, the Ministry of Agriculture, the Colonial Office and the Medical Research Council, as well as of various scientific societies. They have undertaken special pieces

of research for the Agricultural Research Council, the Ministry of Agriculture and the Ministry of Supply, and have prepared reports or papers for the Agricultural Research Council, the Agricultural Improvement Council, the Ministry of Information and the British Council. In February, 1945 at the invitation of the Portuguese Ministry of Agriculture Mr. F. C. Bawden visited Portugal under the auspices of the British Council, where he gave lectures at Lisbon, Oporto and Coimbra.

A large amount of diagnostic work has been done at the request of Provincial Advisory Officers and others.

Viruses and virus diseases

Before the war the work of the Department on viruses dealt exclusively with such problems as their relationships with their insect vectors, the cytology of infected plants, the purification of the viruses and the study of their chemical, physical and serological properties. All these lines of work have been continued since 1939 as far as possible, but in addition much attention has been paid to field work, especially with potatoes and sugar beet, in attempts to elucidate the factors affecting the rate of spread of virus diseases in these crops and, if possible, to design control measures. In conjunction with this field work, much of our glasshouse accommodation was also given over to experiments on the virus diseases of these crops.

Laboratory work

During the period under review considerable attention has been paid to studying the factors affecting the liberation of viruses from infected plant tissues. In the past all work has been done on the virus contained in the sap, and the fibrous residues have been assumed to be virus-free, as no further virus is obtained by extracting them with water or buffer. These residues, however, may contain more virus than the sap, but it is held in an insoluble form. It can be released by fine grinding or, better, by incubation with certain proteolytic enzymes (34, 35, 36). Work on different kinds of extract from plants suffering from tobacco mosaic has provided further evidence showing how readily tobacco-mosaic virus aggregates. By differential ultra-centrifugation the virus can be separated into fractions differing widely from one another in infectivity and in their physical and serological properties. Preparations of tobacco-mosaic virus have been made that show little or no anisotropy of flow and sediment slowly in the centrifuge ; these are unstable and pass into forms that are anisotropic and sediment rapidly. Electron micrographs show that this change is accompanied by a great increase in the average length of the virus particles.

Electron micrographs have been made of a number of different plant viruses ; these have confirmed many earlier deductions about the sizes and shapes of virus particles. Much research, however, has been needed on the machine itself. Because of their small size and power of stopping electrons, plant viruses are difficult subjects for study with the electron microscope and considerable attention has therefore been given to devising methods which give

better resolution (38). In addition to viruses, electron micrographs have been made of clay minerals, lung residues, bacteria and specially prepared sections of biological materials.

Tobacco necrosis has been found to be a disease that is caused by a number of serologically unrelated viruses. Several of these have been isolated in the form of crystalline nucleoproteins. Most crystallise when precipitated slowly with ammonium sulphate in the cold, but one fails to crystallise with this treatment. This virus, however, readily crystallises when ultra-centrifuged or when kept in concentrated salt-free solutions. It has smaller particles than any virus previously studied, and is also unusual in that many treatments destroy infectivity without affecting its serological activity (17, 31, 35).

The inactivating effects of a wide range of different treatments have been studied (29, 30, 33, 52, 58). Some treatments readily destroy the infectivity of all the viruses used while leaving their general physical and serological properties unaffected. Other treatments do this with tomato bushy-stunt and tobacco-necrosis viruses, but not with tobacco-mosaic or potato-virus X, although with all treatments infectivity is the first property to be affected. Inactivation of tobacco-mosaic virus and potato-virus X is usually accompanied by the separation of nucleic acid from the protein, but inactivation of bushy-stunt virus is not.

The serological reactions of anisotropic viruses such as tobacco-mosaic virus resemble in every way those of bacterial flagellar-type antigens, whereas those of viruses with spherical particles resemble those of somatic antigens. New interpretations of the different behaviour of these two types of antigen have been advanced as a result of the serological studies made on the virus preparations. Viruses and antibodies have been shown to form complexes with other proteins, and it has been possible to change normal precipitating antigens into non-precipitating forms (23, 24, 25, 26, 55, 56, 57, 59, 60, 61). With one and the same antiserum, preparations of tobacco-mosaic virus have been shown to behave like flagellar or somatic antigens, depending on whether or not they show anisotropy of flow and contain elongated particles, Clearly the different behaviours depend on the antigens and not as previously thought, on properties of the antibodies (36).

Antisera were prepared that reacted specifically with the sap of plants suffering from sugar-beet yellows. This is the first time that serological methods have been applied to a virus not transmitted mechanically, and it allowed the properties of the virus to be studied (63). Attempts to apply the method to strawberry viruses failed, possibly because of difficulties of extracting the viruses from infected plants (27).

Cytological studies were made of the inclusion bodies formed by several different viruses. Previously undescribed forms of cytoplasmic inclusions were found in plants infected with various strains of tobacco-mosaic virus (53). Tobacco-etch viruses were found to produce crystalline inclusions in the nuclei of infected cells, the first time this phenomenon has been found in virus diseases of plants though in animals it is common, and the properties of these inclusions were studied (47, 20, 67). Inclusions were found

for the first time in plants infected with potato-virus Y, and the form of those produced by virus X was found to vary with different strains and different hosts (37). In addition to the study of inclusions, cytological investigations were made of the characteristic blotches formed by Arran-Pilot potatoes (69) and of the phloem necrosis found in leaf-roll potatoes (70).

Glasshouse work

The relationships between the following viruses and their vectors were studied :—potato-virus Y, cucumber-virus 1, hyoscyamus-virus 3, tobacco-etch viruses, lettuce-mosaic virus, sugar-beet-mosaic virus, dandelion-mosaic virus and sugar-beet-yellows virus (48, 49, 51, 64, 71, 72, 73, 74, 75). Except for the last two, all behaved similarly ; the efficiency of all vectors of the first six was much increased by a preliminary period without feeding, followed by a feeding period on the infected plant of only a few minutes. These viruses do not persist long in the vectors, though aphides prevented from feeding sometimes remain infective for 12 hours. Dandelion-yellow-mosaic virus also does not persist in the aphis, but the efficiency of its vectors is not increased by preliminary fasting, as they need to feed on the infected plants for some hours before they become infective. Sugar-beet-yellows virus behaves quite differently. The efficiency of its vectors increases with increasing time spent on the infected plant. There is no response to a preliminary period without feeding, and the aphides remain infective longer when feeding continuously than when deprived of food : vectors can remain infective for as long as three days after feeding on a diseased plant.

Experiments were also made on the insect transmission of potato-leaf roll, pea mosaic, pea-enation mosaic, soya-bean mosaic and of strains of viruses found attacking brassicae. A new aphis, provisionally named *Myzus ascalonicus* (the Shallot Aphis), was described and its ability to transmit a number of different viruses compared with that of *Myzus persicae*, which the new aphid superficially resembles (40).

Work on the viruses causing necrotic diseases of the potato showed that potato-virus B is a strain of virus X and that virus C is a strain of virus Y (37). Virus C, however, was not transmitted by any of the aphides that transmit virus Y. The variation in symptoms shown by plants in the field infected with virus Y was found to be a result of the occurrence of this virus in a number of strains : in Majestic potatoes the symptoms caused by these vary from a barely perceptible mosaic with no necroses in the first year of infection to a severe form of leaf-drop streak. Different potato varieties were shown to vary in their susceptibility to potato-virus Y, and a glasshouse test using aphides was designed for comparing varietal susceptibility (23) : this gave reproducible results, comparable with those obtained in field trials, and may prove useful in breeding for resistance.

A new type of interaction between viruses was described in plants infected simultaneously with tobacco-etch viruses and potato-virus Y. Severe-etch virus protects plants against virus Y, but plants infected with virus Y are susceptible to severe-etch virus.

Severe-etch virus apparently suppresses virus Y and replaces it even in tissues where it was well established (20, 21). Further evidence was obtained that the degree of protection afforded to a plant by one strain of a virus against infection with another is proportional to the concentration of the first strain in the inoculated tissues (65).

A number of viruses which are transmitted by insects are not transmitted mechanically, or are transmitted only when special methods of inoculation are employed. Studies of the factors affecting infection by mechanical inoculation suggest three different explanations of this phenomenon ; the extracts of some host plants are such that viruses are inactivated (27) : the virus content of extracts of plants infected with some viruses is below the dilution end point (48, 51) : some viruses may need to enter deep-seated tissues before they cause infection (51, 64). The susceptibility of plants to infection can be varied by altering the physiology of the host (45), and the effects of nutrition of the host on susceptibility are now being studied.

Field Work

This has been the main new line of work on virus diseases and has been intensively pursued since 1940. Annual surveys of insects and virus diseases of commercial crops of potatoes and sugar beet have been made, together with many different types of experiment to determine the factors influencing the rate of spread of viruses.

In collaboration with Provincial Advisory Mycologists and others, experiments on the same general plan have been conducted in different parts of the country. Plots of healthy potatoes containing a standard amount of infected plants were laid out, and samples were lifted at fortnightly intervals. In this way much information has been gained on the normal growth of the potato plant (41, 41a) as well as on the extent of spread of potato leaf roll and potato-virus Y in different districts and on the date at which spread occurs. Spread is mainly over small distances, so that a few infected plants within a crop are much more important than badly affected stocks at a distance. This suggested the importance of self-sets as sources of virus diseases : in many districts these have been found to survive in large numbers for some years. The health of such self-sets seems to depend on the health of the crop from which they came, for when growing in crops such as cereals, isolated potato plants do not seem to contract virus diseases at all rapidly.

After the severe winters of 1939-40 and 1940-41, there was little spread of potato-virus diseases, but after the mild winters of 1941-42 and 1942-43, when *Myzus persicae* overwintered on brassica and other crops, there was a much greater spread. No close correlation was found between the total aphis infestation and the amount of spread of virus diseases. The work has shown the great importance of *M. persicae* as a vector and the results so far suggest that most of the spread may be caused by the winged migrants rather than by the wingless individuals that make up most of the infestation. Much of the spread in the south and east of England occurs early

in the season, which no doubt explains the relative failure in experiments to control the diseases by such measures as roguing, early lifting and fumigation with nicotine.

Much of the field work on sugar beet has been carried out in collaboration with Dr. R. Hull of the Midland Agricultural College. The results of field observations have closely paralleled those with potato crops and again suggest the importance of *M. persicae* as a vector. In 1940, '41, '42, there was very little virus yellows in the root crop until late in the season, and there were virtually no *M. persicae* found. This aphis, however, overwintered on stecklings in 1942 and in 1943 was observed in large numbers on the root crops. In this year there was a severe outbreak of virus yellows in the districts where seed crops were grown, but it was slight elsewhere. There was some correlation between the health of root crops and the infestation of *M. persicae*, but much closer correlation between health and the number of winged *M. persicae* caught on the sticky aphis traps.

In 1944 there was an early and widespread epidemic of yellows, extending to districts remote from those growing seed. Although there was a severe infestation of *Aphis fabae*, which may have helped to spread the disease, this was not of primary importance, for extent of the disease was correlated with the incidence of *M. persicae*, though the infestation of this was much smaller than that of *A. fabae*. In 1945 there was again an infestation of *M. persicae* and where this was heavy, especially in the vicinity of seed crops, there was again a severe attack of yellows (43, 44).

Field trials have shown the importance of early sowing to offset the loss by yellows (72), and methods have been devised to distinguish yellows caused by virus infection from chlorosis produced by other causes (42, 63).

Mycology

During the period under review, most attention was given to plant diseases caused by soil-borne fungi. The majority of root-infecting fungi are highly specialised parasites, and their life history is divided into two sharply contrasting phases (i) an active parasitic phase on the underground parts of the host plant, during the growing season of a susceptible crop (ii) a non-parasitic phase, as saprophytic mycelium in infected plant residues, or as resting spores or sclerotia, during which the numbers of the plant parasite are progressively reduced. Although most time was given to the study of such specialised root-infecting fungi, as responsible for the most important soil-borne diseases of field crops, work was also done with certain less specialised saprophytic fungi, in which parasitism of crop plants was incidental to their life as regular soil saprophytes.

In continuation of work on the parasitic activity of *Ophiobolus graminis*, the loss in yield of wheat due to the take-all disease was shown to be aggravated by deficiencies of N, P or K in a sand-culture experiment (85). The survival of this fungus in infected wheat stubble buried in the soil was found to depend chiefly upon supply of nitrogen from the surrounding soil adequate to maintain continued mycelial development in the infected tissues. This supply of nitrogen was reduced, and the life of *O. graminis* curtailed, by

incorporation of nitrogen—poor but easily decomposable organic materials with the soil—or by the growing of non-susceptible plants (84, 87). These conclusions are being tested in a field experiment in progress at the Woburn Experimental Station, on light land favourable for the development of take-all. During the war interest in take-all centred upon the likelihood of its development in wheat and barley crops taken after ploughed-up grassland. A test was therefore made of the longevity of *O. graminis* on the roots of a number of common pasture and weed grasses; timothy (*Phleum pratense*) was the only species which could be considered a non-carrier, though the rye grasses (*Lolium* spp.) did far less damage as take-all carriers than did the common bent grasses (*Agrostis* spp.) (86). During the war, losses from take-all in wheat and barley crops were greatest in 1943: a survey of this disease in the Southern Advisory Province emphasised the danger of weed-grass hosts nullifying the effect of crop rotations otherwise adequate for control of this disease (81). Although in England oats are immune to take-all, and can be used in the rotation for reducing carry-over of *O. graminis*, in Wales this crop is susceptible. This was shown to be due to the common occurrence in Wales of a distinct variety of the take-all fungus, *Ophiobolus graminis* Sacc. var. *Avenae*, E. M. Turner, which has been described and named (104). The oat-attacking variety was also found to be widely distributed in Scotland, where the second consecutive crop of oats after grass may suffer severely from take-all (88).

Another fungus causing root and foot rot of cereals is *Fusarium culmorum*. This disease is sometimes seed-borne, and the seedling blight is likely to be serious only when seed is sown without any fungicidal treatment: it was found to be most severe under soil conditions unfavourable to the cereal seedling, such as low soil moisture, acidity, or shortage of plant nutrients, especially nitrogen (103). Similarly, foot rot of older plants is uncommon except in unduly wet or dry soils, or in acid soils. In contrast to *O. graminis*, *F. culmorum* was shown to be a common soil saprophyte, and an important coloniser of healthy wheat stubble when ploughed under the soil (101). *Penicillium* spp. were found to be of equal importance with *F. culmorum* as colonisers of the wheat stubble: their relative preponderance on the isolation plates depended upon the method of surface sterilisation employed (105).

Another common soil fungus, *Rhizoctonia solani*, was also shown to exist as a free-living saprophyte in the soil (80). Its growth on Rossi-Cholodny slides was most rapid at a relatively low soil-moisture content, and was favoured by good soil aeration. Although the fungus was found capable of growing indefinitely through untreated fallow soil as a free-living saprophyte, its activity was reduced by addition of certain organic materials to the soil, apparently through the competition of other organisms better fitted to decompose such material.

In contrast to these saprophytic root-infecting fungi is the Myxomycete *Plasmodiophora brassicae*, which seems unable to live as a saprophyte, and survives in the soil in between susceptible cruciferous crops in the form of resting spores. The effect of soil

conditions upon infection of cabbage seedlings was studied by the infected-root-hair count method: soil conditions, such as high alkalinity and low moisture, which were well known to be unfavourable to the development of clubroot in pots and in the field, also gave low infected-root-hair counts (102). This technique is now being used in a study of the survival of the resting spores of *P. brassicae*. The survival of another type of organ, the multicellular sclerotium, is being studied in the fungus *Helicobasidium purpureum*, responsible for violet root rot of sugar beet and other crops.

In 1939 we were asked by the Empire Cotton Growing Corporation to undertake a general inquiry into wilt disease caused by *Verticillium* spp., because of the increase of this trouble in cotton fields in Uganda and elsewhere. The investigation was carried out with tomato plants grown under glass. Development of wilt was favoured by soil of high available–nitrogen content, and by high light intensity and other conditions making for rapid carbon assimilation by the host plant. Evidence was obtained in favour of the hypothesis that an infected plant does not become infectious to its neighbours until it becomes moribund, and the wilt fungus emerges from the vascular cylinder into the cortex of the host (99, 100).

In addition to the investigations on root-infecting fungi, work was carried out on several other fungi which, though not root-infecting, are at least partially soil-borne. In 1943, we co-operated in the survey of wastage in potato clamps carried out by Drs. A. R. Wilson and A. E. W. Boyd, of the Midland Agricultural College. This co-operation was at first confined to the making of fungus isolations from various types of potato-tuber rots, but when a rot caused by *Fusarium avenaceum* was found to be quite prevalent, though hitherto unreported from this country, comparative experiments on rotting by this fungus and by the dry-rot organism, *Fusarium caeruleum*, were started. Whereas optimum temperature for rotting by *F. caeruleum* was found to be 15°C., that for *F. avenaceum* was 20°-25°C. The fact that *F. avenaceum* is less common as a cause of potato wastage than is *F. caeruleum* was attributed not only to its relative inactivity at temperatures below 15°C., but also to its requirement of a high atmospheric humidity for development of rotting (98).

The fungus *Cercosporella herpotrichoides*, causing the eyespot disease of cereals, is partially soil-borne, inasmuch as the fungus is spread by spores formed in damp weather on infected stubble, half-buried or left lying on the surface of the soil by faulty ploughing. The disease does not affect the roots, but only the stem, eyespot lesions being formed most commonly just above soil level. As the fungus is dispersed by spores, its spread from a few initial foci of infection in a young crop is more rapid than the subterranean mycelial spread of the take-all fungus, *Ophiobolus graminis*, which passes only slowly from root to root. A crop rotation long enough to control take-all is therefore quite inadequate to control the more rapidly spreading eyespot disease. Evidence on the distribution of eyespot suggests, however, that the spores of the fungus are spread by rain splash rather than by air currents, as dispersal from initial foci of infection seems to occur only within the crop, and does not usually involve

other crops on adjacent fields. In agreement with this is the decline in prevalence of the disease with less frequent occurrence of susceptible cereal crops in the rotation, as shown in extensive surveys of this disease made in 1941 and 1944 (90, 94). Certain varieties of wheat with a shorter straw, such as Wilma and Vilmorin 27, are somewhat resistant to the eyespot disease: outstanding in this respect is the very short-strawed variety Desprez 80. The apparent resistance of these varieties may be due in part to the lower relative humidity of the air near soil level under such short-strawed varieties. Much evidence has been accumulated that any measure which reduces relative humidity of the air around the tiller bases tends to decrease infection by the eyespot fungus. Such measures are late sowing of winter wheat, reduced rate of drilling, wide spacing of rows, shallow drilling, and attention where necessary to soil drainage. The checking of forward growth in the spring by feeding-off with sheep, mowing, or spraying with sulphuric acid, is also sometimes beneficial in checking infection (91-93). Application of nitrogenous fertilisers increases tillering, and so tends to increase the incidence of eyespot: the increased incidence of disease is more than offset, however, by the increase in yield of grain from infected as well as from healthy plants (96). A new disease resembling eyespot has been described, and the causal fungus identified as *Corticium* (*Rhizoctonia*) *solani*. This disease, which has been named "sharp eyespot," is not of great economic importance, as it seldom affects more than 1 per cent. of the straw in any crop, and does not seem to increase with the frequency of susceptible crops in the rotation, as does true eyespot (75).

Trials of the effect of certain dyestuffs on spore germination in *C. herpotrichoides* led to more comprehensive tests of these dyestuffs as inhibitors of spore germination in *Fusarium culmorum*, which proved a more satisfactory test organism. This work was carried out in collaboration with the Department of Insecticides and Fungicides (82).

PUBLICATIONS

VIRUS DISEASES

BOOKS

1. Bawden, F. C. 1939. *Plant viruses and virus diseases.* First edition, pp. 272 XVI, Chronica Botanica Co., Leiden, Holland.

2. Bawden, F. C. 1943. *Plant viruses and virus diseases.* Second edition, pp. 294 XIV, Chronica Botanica Co., Waltham, Mass., U.S.A.

REVIEWS

3. Bawden, F. C. 1939. *Some recent work on plant viruses.* Emp. J. Exp. Agric., **7**, 1-10.

4. Bawden, F. C. 1940. *The sizes of plant viruses.* Chron. Bot., **6**, 13-14.

5. Bawden, F. C. 1940. *Some properties of plant viruses.* Chem. Ind., 788-89.

6. Bawden, F. C. 1941. *Virus diseases of the dahlia.* The Dahlia Year Book, 20-26.

7. Bawden, F. C. 1942. *Potato virus diseases.* Nature **150**, 476-77.

8. Bawden, F. C. 1942. *Crystallography and plant viruses.* Nature **149**, 321-22.

9. Bawden, F. C. 1945. *The nature of viruses.* Sci. Month., **60**, 48-50.

10. Bawden, F. C. 1945. *The potato and its ailments.* School Sci. Rev., No. 101, 62-75.

11. Bawden, F. C. 1945. *Plant viruses and virus diseases.* Nature, **155**, 156-60.

12. Bawden, F. C. and N. W. Pirie. 1938. *Plant viruses I. Serological, chemical and physico-chemical properties.* Tabulae Biologicae, **16**, 355-71.

13. Pirie, N. W. 1945. *Physical and chemical properties of tomato bushy stunt virus and the strains of tobacco mosaic virus.* Adv. Enzymology, **5**, 1-29.

14. Sheffield, F. M. L. 1944. *The nucleolus.* Nature, **153**, 687-88.

15. Sheffield, F. M. L. 1944. *The electron microscope and its use in biological research.* School Sci. Rev., No. 96, 201-9.

16. Smith, J. Henderson. 1938. *Some recent developments in virus research.* Ann. Appl. Biol., **25**, 227-43.

SCIENTIFIC PAPERS

17. Bawden, F. C. 1941. *The serological reactions of viruses causing tobacco necrosis.* Brit. J. Exp. Path., **22**, 59-70.

A method is described for the purification of tobacco necrosis viruses that leads to little or no loss of infectivity. Evidence is presented showing that tobacco necrosis is a disease that can be caused by a number of serologically unrelated viruses. All the viruses used failed to crystallise, and it is shown that the virus culture from which Pirie *et al.* in 1938 obtained crystals was a mixed one. It is suggested that the serologically distinct tobacco necrosis viruses have particles of different sizes, and that they may differ in stability. The behaviour of the tobacco necrosis viruses on heating, ageing or treating with dilute alkali differs from that of potato virus "X," for the former are rendered non-infective without being denatured, and they remain fully active antigenically.

18. Bawden, F. C. 1941. *Problems in breeding for disease resistance.* Chron. Bot., **6**, 247-8.

A note on the value of breeding for hypersensitivity.

19. Bawden, F. C. 1943. *Some properties of the potato viruses.* Ann. Appl. Biol., **30**, 82-83.

An abstract of a paper given at a symposium on potato virus diseases.

20. Bawden, F. C. and Kassanis, B. 1941. *Some properties of tobacco etch viruses.* Ann. Appl. Biol., **28**, 107-18.

The symptoms of severe and mild etch are described; plants suffering from either contain both intranuclear and cytoplasmic inclusions. Fewer and larger crystals are formed in the nuclei of plants with mild etch. Plants infected as seedlings with S.E.V. develop malformed leaves, in which the cytoplasmic inclusions crystallise to give rise to birefringent needles. M.E.V. protects plants against infection with S.E.V.; the two are serologically related, for antisera prepared against either reacted with S.E.V. Precipitation was not obtained with M.E.V., presumably because the virus content of sap is too small.

Although not serologically related to potato virus Y or Hyoscyamus virus 3,

S.E.V. has similar properties in vitro and is transmitted in the same way. The interactions of these three viruses in the plant suggests that they are related. Plants infected with either of the other viruses are not protected against S.E.V., and those infected with P.V.Y. are susceptible to HY.V.3. Plants infected with S.E.V., however, are protected against the other viruses, and those infected with HY.V.3 are protected against P.V.Y. S.E.V. is able to suppress these two viruses when healthy plants are infected with a mixed inoculum, and to supplant them in tissues in which they are already established. Similarly, HY.V.3 can suppress and supplant P.V.Y. Possible interpretations are given for these results. S.E.V. has asymmetrical particles, for concentrated preparations showed anisotropy of flow.

21. Bawden, F. C. and Kassanis, B. 1945. *The suppression of one plant virus by another.* Ann. Appl. Biol., **32**, 52-57.

Severe etch virus prevents the multiplication of potato virus Y and Hyoscyamus virus 3 and replaces them even in plants in which they are established. Mild etch virus reduces the concentration of potato virus Y but does not suppress it completely. Cucumber virus 1 multiplies normally in mixed infections with any of the three other insect-transmitted viruses. Possible implications of these results on the mechanism of virus multiplication are discussed; it is suggested that these viruses inactivate in cell sap at approximately the same rate as they denature *in vitro*.

No differences were found between the stability of antibodies to viruses with different properties.

22. Bawden, F. C. and Kassanis, B. 1946. *Varietal differences in susceptibility to potato virus Y.* Ann. Appl. Biol., **33**, 46-50.

In addition to giving different kinds of symptoms when infected with potato virus Y, individual potato varieties also differ in their susceptibility to infection, in the concentration of virus attained in their sap, and in their efficiency as sources of virus for aphides. Their relative susceptibility in the open when exposed to equal chances of infection is correlated with the ease with which they become infected when colonised with infective aphides, and can be assessed from tests made under glass. Methods for making such tests are described; these need few tubers and give reproducible results. It is considered that they could be applied in studying the inheritance of this type of resistance and to test the behaviour of new seedlings. The American variety Katahdin was the most resistant of those tested, but there were significant differences between commerical British varieties.

In the open, all varieties were equally colonised by aphides and resistance to infection with virus Y was not correlated with resistance to leaf roll.

23. Bawden, F. C. and Kleczkowski, A. 1941. *Non-precipitating protein antigens.* Nature, **148**, 593-94.

When tomato bushy stunt virus or serum globulin is heated with albumin the products cease to precipitate with antiserum to the virus or globulin, though they still fix complement. Such products are still antigenic and when injected into rabbits produce antisera that precipitate the virus or globulin respectively.

24. Bawden, F. C. and Kleczkowski, A. 1941. *Some properties of complexes formed when antigens are heated in the presence of serologically unspecific proteins.* Brit. J. Exp. Path., **22**, 208-19.

When tomato bushy stunt virus, human serum globulin and albumin are heated at temperatures around 80° C. in the absence of serologically unspecific proteins, they are still able to precipitate with their specific antisera. If heated in the presence of serologically unspecific serum albumin, however, they produce complexes behaving like non-precipitating haptens. Human globulin, and albumin behave in this way after being heated for 5 minutes at 100° C., but bushy stunt virus does not combine with antibody after heating for 10 minutes at 95° C.

The presence of albumin in solutions of tobacco mosaic virus heated at pH 7·0 reduces the rate of inactivation, but this flagellar type antigen still flocculates with its antiserum. This virus loses its ability to combine with antibody after 10 minutes at 90° C.

Heating either virus in the presence of albumin prevents the separation of

precipitates of denatured protein, and that combination between the viruses and albumin occurs is shown by the fact that the viruses can then be removed by precipitation with antiserum to the albumin.

25. Bawden, F. C. and Kleczkowski, A. 1942. *The antigenicity of non-precipitating complexes.* Brit. J. Exp. Path., **23**, 169-78.

Bushy stunt virus and human serum globulin remain antigenic when changed into non-precipitating complexes by heating with rabbit albumin in suitable conditions. The injection of such complexes into rabbits produces antisera apparently identical in all their serological reactions with those produced against the normal virus or globulin. Solutions of the non-precipitating antigens fix complement with antisera as strongly as solutions of the normal precipitating antigens, showing that complement fixation does not depend on the formation of insoluble material. Sufficient heating destroys most of the original antigenicity of bushy stunt virus and globulin, but there is no evidence that heating creates any new specificity

26. Bawden, F. C. and Kleczkowski, A. 1942. *The effects of heat on the serological reactions of antisera.* Brit. J. Exp. Path. **23**, 178-88.

The effect of heat on serological reactions of antisera to O-type antigens (bushy stunt virus and human serum globulin) and to an H-type antigen (tobacco mosaic virus) were studied.

The complement-fixation power of all antisera, and the specific neutralization of infectivity by virus antisera, were equally effected by heat. Tobacco mosaic virus antisera lost all their serological reactions almost simultaneously, but with O-type antigens less heating was needed to destroy precipitability than to destroy other serological reactions.

These results are explained by the formation of complexes between antibodies and other serum proteins during heating. Mixed complexes, formed with albumin, combine with antigens but are unable to fix complement, neutralize infectivity or cause precipitation; they inhibit the precipitation of O-type antigens by other antibodies, but do not interfere with complement fixation. Antisera partly denatured by heat contain mixtures of antibodies in different states; a small proportion of mixed complexes prevents the precipitation of O-type antigens, but has little effect on complement fixation or on the precipitation of H-type antigens.

27. Bawden, F. C. and Kleczkowski, A. **1945.** *Protein precipitation and virus inactivation by extracts of strawberry plants.* J. Pom. Hort. Sci., **21**, 2-7.

Specific antisera could not be produced against extracts of virus-infected strawberry plants, possibly because of properties of the host plant. No soluble protein could be extracted from fruit, leaves, runners and roots; and aqueous extracts from all organs reduced the infectivity of tobacco mosaic virus. Except those from the fruit, all extracts contained much tannin and they precipitated serum proteins. The possible effect of this on failure to transmit strawberry viruses by mechanical inoculation is discussed.

28. Bawden, F. C. and Pirie, N. W. 1939. *The purification of insect-transmitted plant viruses.* Brit. J. Exp. Path., **20**, 322-29.

Liquid crystalline preparations of nucleoproteins have been made from the sap of tobacco plants infected with the two insect-transmitted viruses, potato virus "Y" and Hyoscyamus virus 3. The yields are from 0·5 to 3·0 mg. per litre of infective sap. These proteins give specific precipitates, of the flagellar type, with antisera when diluted to $1 \cdot 10^6$. They are infective, but the methods used in the purification processes seem to destroy the infectivity of much of the virus without destroying its serological activity. The chemical and physical properties of preparations of these viruses closely resemble those of potato virus "X." Some properties of a lipoid-containing contaminant are described.

29. Bawden, F. C. and Pirie, N. W. 1940. *The inactivation of some plant viruses by urea.* Biochem. J., **34**, 1258-77.

The literature on the effects of urea on proteins, tissues, bacteria and viruses is reviewed. The four viruses, tobacco mosaic, potato "X," tomato bushy stunt and tobacco necrosis, are irreversibly denatured by urea. The denaturation is accompanied by loss of infectivity and serological activity. For each

virus there is a critical concentration of urea below which there is no irreversible effect on infectivity. This concentration is smallest for potato virus " X " and greatest for tomato bushy stunt virus. The rate of inactivation is greatly increased by the presence of alkali. The rate of inactivation is minimum at about 20°C., and is much increased by cooling to 10°. The inactivation of purified tobacco mosaic virus by urea proceeds only slightly more slowly than that of virus in crude infective sap. The inactivation of tobacco mosaic virus and potato virus " X " is accompanied by separation of the nucleic acid and protein, but the inactivation of bushy stunt and tobacco necrosis viruses is not. Changes in the absorption spectra that accompany inactivation are described.

30. Bawden, F. C. and Pirie, N. W. 1940. *The effects of alkali and some simple organic substances on three plant viruses.* Biochem. J., **34**, 1278-92.

The effects of alkali and of 15 simple organic substances on tobacco mosaic virus and tomato bushy stunt virus are described. Some experiments with potato virus " X " are also included. Bushy stunt virus is the most resistant to denaturation and potato virus " X " the least. The effects of alkali on tobacco mosaic virus are complex ; gentle treatment may increase infectivity, slightly more severe treatment causes loss of infectivity but not loss of serological activity, and more severe treatment causes loss of all characteristic properties. With bushy stunt virus inactivation without loss of serological activity occurs over a wider pH range, and crystalline non-infective preparations can be made from alkali-treated material. Apparently similar crystalline and non-infective preparations can be isolated from expressed sap allowed to age for some months. In the presence of alkali, sodium dodecyl sulphate readily destroys all the viruses, separating the nucleic acid from the proteins. With the exception of nicotine and arginine, which form with tobacco mosaic reversible, fibrous precipitates, all the substances we have tested at concentrations below 4M inactivate the viruses in neutral solution. Dilute solutions of these agents are often precipitants whereas concentrated ones dissolve the products of denaturation. Inactivation of tobacco mosaic virus and potato virus " X " is usually accompanied by the separation of the nucleic acid from the protein, but inactivation of bushy stunt virus is not.

31. Bawden, F. C. and Pirie, N. W. 1942. *A preliminary description of preparations of some of the viruses causing tobacco necrosis.* Brit. J. Exp. Path., **23**, 314-28.

The purification of six separate cultures of viruses causing tobacco necrosis is described ; these cultures have been labelled Potato, Princeton, Tobacco VI, Rothamsted, Tobacco I and Tobacco II. The last two are probably identical, but the remainder differ in their properties, although they produce identical symptoms in tobacco and bean. The first three share antigens but are serologically unrelated to the others, suggesting that the disease can be caused by different viruses, each of which may occur in a number of strains. On precipitation with ammonium sulphate the products from four cultures have behaved systematically : Rothamsted gives an amorphous precipitate ; Princeton shows anisotropy of flow but gives no recognisable crystals ; potato crystallises as thin lozenge-shaped plates ; and tobacco VI as hexagonal prisms. Tobacco I and II, for unknown reasons, crystallise in a variety of different forms. The two commonest are dodecahedra and bipyramids, but thin round laminae and elaborately twinned structures also occur. The materials isolated from all the cultures of tobacco necrosis seem to be essentially nucleo-proteins.

32. Bawden, F. C. and Pirie, N. W. 1943. *Methods for the purification of tomato bushy stunt and tobacco mosaic viruses.* Biochem. J., **37**, 66-70.

Methods, requiring only low-speed centrifuges, are described for the purification of tomato bushy stunt and tobacco mosaic viruses.

These preparation appear to contain virus that is weight for weight as infective as that in clarified sap. There is evidence, however, that the tobacco mosaic virus particles have undergone some aggregation.

33. Bawden, F. C. and Pirie, N. W. 1943. *The inactivation of tomato bushy stunt virus by heating and freezing.* Biochem. J., **37**, 70-79.

Tomato bushy stunt virus loses its infectivity when heated insufficiently to cause denaturation and loss of serological activity. The temperature coeffi-

cient for the loss of infectivity is small and for loss of serological activity is large. The amount of heating needed for denaturation varies with the pH.

No differences have been found between the chemical and physical properties of non-infective, but serologically active, material and those of fully active preparations.

The rate of inactivation by freezing is increased by increases in the concentration of the virus, in the duration of freezing and in the acidity of the fluid. The virus is protected from inactivation by salts and some other substances. The efficiency of different salts depends on the salt : ice : water eutectic temperature.

In general, loss of infectivity is accompanied by the separation of precipitate and loss of serological activity, but in some conditions freezing destroys infectivity without altering serological activity.

34. Bawden, F. C. and Pirie, N. W. 1944. *The liberation of virus, together with materials that inhibit its precipitation with antiserum, from the solid leaf residues of tomato plants suffering from bushy stunt.* Brit. J. Exp. Path., **25**, 68-80.

After the sap has been expressed from minced tomato leaves infected with tomato bushy stunt virus, the solid residues contain approximately as much virus as the sap. This virus is most effectively liberated by incubating the residues with a commercial trypsin preparation and then passing them through a roller mill ; some virus is liberated by either treatment alone. Incubation with " trypsin " greatly increases the amount of virus liberated by milling, whereas extended milling reduces the amount liberated by " trypsin."

Purified preparations of virus from sap and from the solid residues have similar properties. Extracts of milled fibre contain some virus combined with chromoprotein to form a non-precipitating antigen ; such extracts do not precipitate with virus antiserum until the chromoprotein has been removed. Non-precipitating complexes of virus and chromoprotein can be formed by milling fibre of uninfected plants to which purified virus is added.

Extracts of fibre from healthy and infected leaves, which has been incubated with " trypsin," contain material that inhibits the precipitation of bushy stunt virus by its antiserum.

35. Bawden, F. C. and Pirie, N. W. 1945. *Further studies on the purification and properties of a virus causing tobacco necrosis.* Brit. J. Exp. Path., **26**, 277-285.

A nucleoprotein that is not present in the leaves of healthy plants has been isolated from bean and tobacco leaves infected with the Rothamsted culture of tobacco necrosis virus. This has not crystallised when precipitated with salt, but it crystallises slowly from concentrated salt-free solutions or during sedimentation by ultra-centrifugation. It has a sedimentation constant of 49S, smaller than that of other preparations of plant viruses previously studied. The Rothamsted culture of tobacco necrosis virus readily loses infectivity and the relationship between the crystallisable protein and the virus is uncertain. It is most likely that much of the protein is a non-infective derivative of the virus having many physical, chemical and serological properties in common with it.

36. Bawden, F. C. and Pirie, N. W. 1945. *The separation and properties of tobacco mosaic virus in different states of aggregation.* Brit. J. Exp. Path., **26**, 294-315.

It is shown that tobacco mosaic virus aggregates when exposed to constituents of sap and to many other agents. A method is described for extracting virus from infected leaves which greatly minimises aggregation. The virus of such extracts is inhomogeneous and can be separated by differential ultracentrifuging into fractions with widely different properties. The most slowly sedimenting fractions contain much material other than virus nucleoprotein ; the virus in them shows no anisotropy of flow, has serological behaviour resembling that of somatic antigens and only small infectivity. The most rapidly sedimenting fractions contain little except virus nucleoprotein, show anisotropy of flow and have serological behaviour characteristic of flagellar type antigens.

All the fractions are unstable and readily pass into forms that sediment rapidly, show intense anisotropy of flow and have a serological behaviour characteristic of flagellar antigens. In most fractions this change is accom-

panied by the destruction of material other than virus nucleoprotein. It is suggested that the primary virus particle is small and not greatly elongated, and that it occurs in the plant combined with extraneous materials, the removal of which sets free groups capable of combining with one another. Reasons for the variation in infectivity of different fractions are discussed, but no definite conclusions reached.

37. Bawden, F. C. and Sheffield, F. M. L. 1944. *The relationships of some viruses causing necrotic diseases of the potato.* Ann. Appl. Biol., **31**, 33-40.

Potato virus B, and some other viruses with reactions in potato varieties different from any previously described, are strains of virus X. All produce intracellular inclusions which vary with different hosts and virus strains. Except with virus B, the inclusions are larger and more frequent in potato than in tobacco or tomato. All give systemic infection when inoculated to tobacco, tomato and potato varieties in which they are carried or cause mosaic symptoms ; some give systemic infection when inoculated to varieties in which they cause top-necrosis, whereas others give only local lesions.

Potato virus C is a strain of virus Y : in tobacco and a few potato varieties both produce similar symptoms, but in those varieties in which Y causes leaf-drop streak, C causes top-necrosis. C causes systemic infection when inoculated to tobacco and to potato varieties in which it causes mosaic symptoms, but not when inoculated to potato varieties in which it causes top-necrosis. Virus C was not transmitted by *M. persicae*. Viruses C and Y produce a few small intracellular inclusions in potato and tobacco.

Virus A is not related to Y or X : no inclusions were found in plants infected with A alone.

38. Crook, E. M., Sheffield, F. M. L. and Chilton, L. V. 1945. *Photographic plates for use in the R.C.A. electron microscope.* Photographic J. B, **85**, 6-12.

Characteristic curves of a range of Ilford plates to electrons of energies from 15 up to 60 kV have been determined in the R.C.A. Type-B electron microscope by applying to the plates an intensity scale of exposures based upon changes in net beam current. In all cases the curves show a rise of gamma with electron energy. This effect, which is linear over the lower part of the kV range, is attributed to electron absorption by the emulsion layer. It confirms similar findings by von Borries for Agfa and Perutz plates. The dependance of image contrast on electron energy is briefly discussed in relation to image-formation by (*a*) differential absorption, (b) differential scattering. With electrons of 45kV energy, the plates studied exhibited a range of speeds of only 13 : 1 at a density of 2 as compared with a range of speeds to white light of 100 : 1. Speed comparisons from one kilovoltage to another were made possible by adjusting the magnification to give a standard brightness on the fluorescent screen of the instrument at a standard beam current. Some of the plates studied showed signs of a maximum sensitivity to electrons at the higher end of the kV-range, similar to that found by previous workers.

39. Doncaster, J. P. 1943. *VI. The life history of* Aphis (*Doralis*) rhamni *B.d.F. in eastern England.* Ann. Appl. Biol., **30**, 101-104.

The successive stages in the life cycle of *Aphis rhamni* are described in detail. The climatic and other factors which influence migration, and the growth and development of infestations on potatoes, are discussed. Though known to be a vector of Potato Virus Y, *A. rhamni* does not appear to be responsible for the spread of this virus in the field.

40. Doncaster, J. P. and Kassanis, B. 1946. *The Shallot Aphis,* Myzus ascalonicus *Doncaster and its behaviour as a vector of plant viruses.* Ann. Appl. Biol., **33**, 66-69.

A new species of aphis, *Myzus ascalonicus* Doncaster, is briefly described, and compared with *Myzus persicae* Sulz., which it resembles superficially. It has been found on shallots in storage and on onions and other species of plants both in glasshouses and in the open between October and June. Its summer habits and hosts are unknown. In comparative virus transmission tests with *Myzus persicae* it was found that *Myzus ascalonicus* transmits dandelion yellow mosaic virus, which is not transmitted by *M. persicae ;*

and also cucumber virus 1, hyoscyamus virus III and sugar beet yellows virus all of which are transmitted by *M. persicae*. *M. ascalonicus* does not transmit the viruses of potato Y, severe etch, lettuce mosaic and sugar beet mosaic which are transmitted by *M. persicae*.

41. GREGORY, P. H. 1943. *VII. The spread of potato virus diseases in the field.* Ann. Appl. Biol., **30**, 104.

No correlation is found between total aphis population and amount of spread of virus diseases. Much of the spread occurs early in the summer. The chances of healthy plants becoming infected fall off rapidly with increasing distance from diseased plants.

41a. GREGORY, P. H. 1944. *Early planting for increased potato yields.* Agriculture, **50**, 557-559.

A close correlation is shown between the date of planting of Majestic potatoes and the yield obtained at lifting. Ten days delay in planting decreased yield by as much as 3½ tons per acre.

42. HALE, J. B., WATSON, M. A. and HULL, R. 1946. *Some causes of chlorosis and necrosis of sugar beet foliage.* Ann. Appl. Biol., **33**, 13-28.

The symptoms and characteristics of two virus and one fungus disease and four nutritional disorders of sugar beet which cause chlorosis and necrosis of the foliage are described. The causes of the diseases and methods of distinguishing between them have been investigated by analytical, pathological and field experimental methods.

Experiments in which diagnosis was confirmed by serological and spectrochemical methods show that the two often easily confused diseases, sugar beet yellows virus and magnesium deficiency, can be visually distinguished.

Sugar beet Yellows virus reduces the potassium but slightly increases the magnesium content of the leaves.

Magnesium deficiency symptoms are associated with a low magnesium content of the foliage, but may be induced by salt applications without greatly affecting the magnesium analysis.

" Potash " deficiency symptoms are often, but not necessarily, associated with a low potassium analysis and may actually be caused solely by a deficiency of sodium. In the field symptoms are induced by sulphate of ammonia and phosphate applications and may be prevented in some cases by the application of either salt or muriate of potash, in others by salt only.

Some inter-changeability of the functions of potassium and sodium in the plant is suggested.

Manganese deficiency symptoms are associated with a low manganese content of the leaves, which can be readily increased by spraying or injection with manganese sulphate solution, but a high concentration of manganese in the foliage, such as sometimes occurs naturally on acid soils, has a toxic effect.

43. HULL, R. and WATSON, M. A. 1945. *Virus yellows in sugar-beet root and seed crops.* Kirton Agric. J. No. 10, 45-48.

Symptoms of sugar-beet yellows are described and possible control measures are discussed, such as isolating steckling beds from the root crop and aphis control by use of insecticides.

44. HULL, R. and WATSON, M. A. 1945. *Virus yellows of sugar beet.* Agriculture, **52**, 66-70.

Losses of up to 50 per cent. can occur because of yellows, if infection occurs early. The disease is usually more serious in districts where seed crops are grown and the overwintering stecklings seem one of the main sources of virus for the annual root crop. The most important vector is *Myzus persicae*.

45. KALMUS, H. and KASSANIS, B. 1944. *Reduction by carbon dioxide of susceptibility of beans to tobacco necrosis viruses.* Nature **154**, 641-42.

Exposure to an atmosphere containing carbon dioxide reduced the number of local lesions produced by tobacco necrosis viruses, whether plants were inoculated immediately before or immediately after exposure. The effect is temporary ; 4 hours after exposure plants regain their full susceptibility.

46. KALMUS, H. and KASSANIS, B. 1945. *The use of abrasives in the transmission of plant viruses.* Ann. Appl. Biol., **32**, 230-34.

The effect of different abrasives on the transmissibility of several plant viruses was tested. Celite and animal charcoal were as effective as carborundum in increasing the number of lesions produced by a given inoculum; 400-mesh carborundum was the most effective among the different sizes which were tested; this gave a result equivalent to increasing the virus content a hundred times. Some preparations of carborundum and charcoal reduced infectivity.

Uninjured plants resisted infectivity when virus solutions were sprayed over them. Leaves previously rubbed without abrasives developed only few lesions whereas leaves rubbed with abrasives developed large numbers. Three hours after rubbing with abrasives, leaves had regained their resistance to sprayed virus solutions.

The effects of rubbing leaves with abrasives are described and their significance discussed.

47. KASSANIS, B. 1939. *Intracellular inclusions in virus infected plants.* Ann. Appl. Biol., **26**, 705-09.

Two kinds of intracellular inclusions in solanaceous plants infected with severe etch virus are described. One occurs in the cytoplasm and is similar to the X-bodies found in many other plant virus diseases. The other occurs only in the nuclei. These intranuclear inclusions appear to be crystalline, have the form of thin rectangular plates, and resemble the inclusions described in the polyhedral disease of silkworms more than any other type of previously recognised virus-inclusion.

48. KASSANIS, B. 1941. *Transmission of tobacco etch viruses by aphides.* Ann. Appl. Biol., **28**, 238-43.

Severe virus is transmitted by *Myzus persicae*, *M. circumflexus*, *Aphis rhamni*, *A. fabae* and *M. gei*. Although the content of mild etch virus in sap is much less than that of S.E.V., both are transmitted to the same extent by *M. persicae*. The percentage of infection using single aphides is greatest with aphides that are starved for 4 hrs. or more and then fed on the source of infection for 2 mins. Continuous feeding on healthy plants or diseased plants greatly reduces the efficiency of the vector. The length of time for which aphides remain infective is also increased from 15 minutes to a few hours if the aphides starve instead of feed; it is also greatly increased in starved insects if they are kept at a low temperature. Provided the feeding time on each test plant is small, one aphis may infect up to four plants.

49. KASSANIS, B. 1942. *Transmission of potato virus by* Aphis Rhamni (*Boyer*). Ann. Appl. Biol., **29**, 95.

It is shown that in glasshouse experiments *Aphis rhamni* is as efficient a vector as *Myzus persicae* in transmitting potato virus Y. The ability of both aphides to transmit is increased by preliminary starving.

50. KASSANIS, B. **1943.** *Neutralisation of some plant viruses by rabbit sera.* Brit. J. Exp. Path., **24**, 152-59.

The unspecific neutralisation of plant viruses by normal and heterologous sera was so large that the additional specific effect of homologous antisera was small in comparison. This specific neutralisation could be used for demonstrating serological relationships only if sera of the same age and stored similarly were compared; the relationships indicated were the same as those indicated by precipitin tests.

Unless sera were kept frozen their unspecific neutralising power fell rapidly on storing. All heterologous antisera reduced infectivity more than normal sera, stored comparably.

Precipitating antibodies did not appear to be responsible for neutralisation. No correlation was found between precipitin titre and neutralising power, and removal of precipitins did not affect neutralisation power. Only quantitative differences were found in behaviour between homologous and other sera; the infectivity of all virus-serum mixtures was regained by dilution.

51. KASSANIS, B. 1944. *A virus attacking lettuce and dandelion*, Nature, **154**, 16.

A description of a new virus, dandelion yellow mosaic, transmitted from dandelion to lettuce by *Myzus ornatus* but not by *M. persicae*. The relationships between the virus and its vector seem different from any previously described.

52. KASSANIS, B. and KLECZKOWSKI, A. 1944. *The effect of formaldehyde and mercuric chloride on tobacco mosaic virus*. Biochem. J. **38**, 20-24.

(1) Tobacco mosaic virus was inactivated by 2 per cent. formaldehyde at all pH values between 3 and 7·5 ; the rate of inactivation was minimal at pH 3·5. Inactivation could be stopped at any stage by dilution or dialysis, but there was no evidence that inactivated virus regained infectivity by these treatments.

(2) Loss of infectivity caused by formaldehyde does not depend on changes in groups giving the Van Slyke test for amino-nitrogen, for preparations inactivated by formaldehyde treatment at pH 3·0 give the same value as control virus. Formaldehyde treatment at pH near 7·0 leads to a greater fall in the Folin pH 8·0 colour value than treatment at pH 3·0. There is no real correlation between the decrease of infectivity and of the colour value.

(3) Mercuric chloride in sufficient concentrations acts as an inhibitor of infectivity. At pH values greater than 6·0 it causes loss of infectivity and serological activity. Dilution, acidification or addition of certain salts prevent inactivation or interrupt its progress at any stage, but there is no evidence that any of these treatments can reverse it.

53. KASSANIS, B. and SHEFFIELD, F. M. L. 1941. *Variations in the cytoplasmic inclusions induced by three strains of tobacco mosaic virus*. Ann. Appl. Biol., **28**, 360-67.

According to previous accounts tobacco mosaic virus regularly induced striate material and amoeba-like inclusions and occasionally raphides in the host cells ; enation mosaic virus gave striate material and amoeba-like X-bodies ; whilst aucuba mosaic virus induced either striate material or a large amorphous inclusion which later gave rise to striate material. A spike-like body recorded in early descriptions of aucuba mosaic disease had not been seen for some years. In 1940, a variety of new forms were induced by all three strains. These new forms were mostly fibrous. The spike-like body reappeared, spindle-shaped bodies, masses of short needle-like fibres and extremely long coiled fibrous forms occurred. New amorphous forms were also found. All these arose either directly or from pre-existing inclusions of the previously recorded types. Variation in the inclusions produced is not due to mutation of the virus. The type of inclusion is to some slight extent determined by the host plant but seems to be largely controlled by the amount of light and heat available to the host.

54. KLECZKOWSKI, A. 1941. *Quantitative studies on the serological reactions of some plant viruses and of a pea nodule bacterium* (Rhizobium leguminosarum). Brit. J. Exp. Path., **22**, 44-58.

Quantitative investigations of serological reactions of tobacco mosaic, aucuba mosaic, and bushy stunt viruses and a strain of pea nodule bacteria, with their homologous antisera, and of cross-reaction between tobacco mosaic and aucuba mosaic viruses, were made.

Antibody-antigen ratios in the precipitate formed at equivalence point by these plant viruses with their homologous antisera occupy an intermediate position between ratios for bacterial agglutination and for precipitation of smaller antigens like ovalbumin or blood serum proteins.

An aucuba mosaic virus antiserum contained antibodies reacting with aucuba mosaic virus but not with tobacco mosaic virus, in addition to antibodies reacting with both, whereas all antibodies in a tobacco mosaic virus antiserum reacted with both viruses.

With the same amount of antibody maximum precipitate with the rod-shaped tobacco mosaic and aucuba mosaic viruses is much greater than with the spherical (or almost spherical) bushy stunt virus, and is formed in much greater antigen excess.

Qualitative differences between strong and weak tobacco mosaic virus antisera were found.

55. KLECZKOWSKI, A. 1941. *The formation of protein complexes in heated solutions of rabbit serum proteins.* Brit. J. Exp. Path., **22**, 188-92.

The effects of heating normal rabbit serum albumin and euglobulin fractions separately and together are described. When a mixture of the two fractions is heated a product is formed with properties different from those of either fraction heated separately. This product is a complex formed by the two fractions uniting as they undergo denaturation.

56. KLECZKOWSKI, A. 1941. *Effect of heat on flocculating antibodies of rabbit antisera.* Brit. J. Exp. Path., **22**, 192-208.

Experiments on the effect of heat on rabbit antisera to the following antigens have been made: human serum albumin and globulin, a strain of pea nodule bacteria (*Rhizobium leguminosarum*); and purified preparations of the following plant viruses—tobacco mosaic, potato "X," tomato bushy stunt and tobacco necrosis.

Antisera to the rod-shaped viruses (tobacco mosaic and potato "X") behave like those to flagellar type antigens, whereas antisera to the other antigens named behave like those to somatic type antigens, much more heating being needed to destroy the flocculating power of the former. However, euglobulin fractions (containing antibodies) of all the antisera behave similarly, and they require more heat to destroy their flocculating power than do the original antisera.

Flocculating antibodies undergo at least two changes during heating. Complexes composed of antibody particles and of particles of other unspecific proteins present in the solutions are first formed. Antibodies changed in this way can still combine specifically with antigens, but the result of this combination depends on the quantity and quality of unspecific proteins present in the solution during heating. Complexes formed when antibodies are heated in the presence of euglobulin fraction of the antiserum flocculate their antigens. Complexes formed when antibodies are heated in the presence of other serum fractions, notably albumin, cannot flocculate their antigens, although they combine with them; this combination interferes with the flocculating action of antibodies that are unchanged. The degree of this interference depends on the type of antigen, being large with antigens of type "O" and small with those of type "H." This fact, and not a difference in heat stability, explains the differences in the behaviour of heated antisera to the two types of antigen.

The second change of antibodies during heating corresponds with a further stage of denaturation and is shown by the loss of ability to combine with antigen.

57. KLECZKOWSKI, A. 1943. *The effect of salts on the formation of protein complexes during heat denaturation.* Biochem. J., **37**, 30-36.

The formation of complexes between different proteins, undergoing heat denaturation together, is greatly influenced by the presence of salts. In the absence of salts only mixtures containing water-soluble serum globulin formed any detectable amount of complexes.

The efficiency of different salts in promoting the complex formation, expressed as the reciprocal of the lowest effective concentration, follows Hardy's law. Ions of higher valency are much more effective than those of lower valency. On the alkaline side of the isoelectric point of the proteins, the efficiency of salts is determined by the valency of the cations, and on the acid side by the valency of anions.

58. KLECZKOWSKI, A. 1944. *Combination of potato virus X and tobacco mosaic virus with pepsin and trypsin.* Biochem. J., **38**, 160-67.

(1) Pepsin combines with potato virus X and casein, which are substrates for its proteolytic activity, but not with tobacco mosaic virus, which is not a substrate.

(2) Tobacco mosaic virus denatured by heat is readily hydrolyzed by pepsin and combines with pepsin almost to the same extent as potato virus X.

(3) Invertase does not combine with potato virus X, with tobacco mosaic virus, whether heat-denatured or not, or with casein.

(4) More trypsin combines with tobacco mosaic virus, which is not a substrate for its proteolytic activity, than with potato virus X, which is a substrate. The combination of trypsin with tobacco mosaic virus could account for the reversible inhibition of infectivity of the virus by trypsin.

(5) Combination between trypsin and tobacco mosaic virus protects trypsin from spontaneous inactivation at pH 7·0.

(6) Trypsin and invertase adsorbed on charcoal can be set free by casein ; invertase can also be extracted by tobacco mosaic virus, but not by sucrose.

59. KLECZKOWSKI, A. 1945. *The reaction of products of initial stages of peptic proteolysis of human and horse serum albumin with antisera to the original albumins.* Brit. J. Exp. Path., **26**, 24-33.

Peptic digestion of human or horse albumin in suitable conditions eventually leads to loss of their ability to react in any detectable way with antibodies to the original albumins. Before this stage is reached some products of peptic proteolysis of the albumins are still able to combine specifically with the antibodies. These products differ from the original albumins in that their precipitability by the antisera to the original albumins is greatly reduced. They do not differ from the original albumins in their diffusion rates. Precipitability of the products by the antisera can be restored by heating solutions of the products in the presence of salt.

60. KLECZKOWSKI, A. 1945. *Conversion of non-precipitating and inhibiting protein complexes into forms again precipitable by the antisera to the original proteins.* Brit. J. Exp. Path., **26**, 33-41.

When tomato bushy stunt virus is heated together with a serum albumin the virus can combine with the albumin to form a complex that does not precipitate with the antiserum to the virus. The virus, which is resistant to peptic proteolysis, can be recovered in the precipitable form by peptic hydrolysis of the complex. Non-precipitating complexes similarly formed between human and horse serum albumin can, in suitable conditions, be split by means of pepsin into forms again precipitable specifically by antisera, although both components of the complex are susceptible to peptic proteolysis.

61. KLECZKOWSKI, A. 1945. *Specific precipitation of one protein by antiserum to another.* Brit. J. Exp. Path., **26**, 41-49.

Products of interaction between human and horse albumin formed during heat denaturation of mixtures of the two, could be precipitated by the antisera to either albumin. The product formed in mixtures, where human albumin was in excess, combined with antibodies to horse albumin, but did not precipitate with them. It precipitated with antibodies to human albumin. The converse of this was true when horse albumin was in excess over human albumin in heated mixtures.

Products of interaction formed between antibodies to bushy stunt virus and human or horse serum albumin, formed when mixtures were heated, could combine, but not precipitate, with the virus, although they could be specifically precipitated with antiserum to the albumin.

62. KLECZKOWSKI, A. and THORNTON, H. G. 1944. *A serological study of root nodule bacteria from pea and clover inoculation groups.* J. Bact., **48**, 661-72.

Twenty-nine strains of nodule bacteria derived from plants of the pea inoculation group, and 161 strains derived from clover nodules, were tested for agglutination with antisera against six strains of nodule bacteria, four derived from clover and two from pea.

No antigen or set of antigens of either O or H type was found to be common to the whole group. Some strains reacted with none of the antisera, some with only one, and others with several antisera, but none with all of them.

Strains belonging to both inoculation groups were found to give agglutination with five of the antisera ; one antiserum reacted only with a small number of strains all from clover.

Neither ability to cross-inoculate between clover and pea host plants, nor effectiveness in fixing nitrogen within the host plant, nor susceptibility to a bacteriophage was necessarily associated with the presence or absence of any one antigen or group of antigens. Indeed, an effective strain and a very ineffective variant derived from it were found to be serologically identical.

There was, however, a partial correlation between effectiveness and the H antigenic constitution.

63. KLECZKOWSKI, A. and WATSON, M. A. 1944. *Serological studies on sugar beet yellows virus.* Ann. Appl. Biol., **31**, 116-20.

Specific antisera have been prepared against the sap expressed from beet plants infected with beet yellows virus.

The antigen is unstable. In the sap it is destroyed by keeping for 2 to 3 days at room temperature or by heating for 10 minutes at 52° C. It is unaffected by pH changes between 5 and 9. In detached leaves at room temperature it remains unchanged for at least 6 days, whereas the ability of aphides to transmit from these leaves fell considerably in 4 days.

The antigen can be reversibly precipitated by ammonium sulphate or sedimented by high-speed centrifugation. However, all the attempts to isolate it from other sap constituents or to concentrate it have failed.

The precipitin reaction is of value for diagnosis, and works successfully with crude sap.

64. ROBERTS, F. M. 1940. *Studies on the feeding methods and penetration rates of* Myzus persicae *Sulz.*, Myzus circumflexus *Buckt., and* Macrosiphum gei *Koch.* Ann. Appl. Biol., **27**, 348-58.

(1) The feeding habits and penetration rates of three aphides *Myzus persicae, M. circumflexus,* and *Macrosiphum gei* on tobacco, and of *Myzus persicae* on sugar beet were investigated in relation to their transmission of *Hyoscyamus* virus III, potato virus Y, cucumber virus I, and sugar beet yellows virus.

(2) Neither *M. persicae* or *M. circumflexus* were found to reach the phloem after 5 minutes feeding on tobacco. Very few *M. persicae* penetrated the phloem in 15 minutes on tobacco or sugar beet. Even after 24 hours a few aphides do not penetrate the phloem but feed on non-vascular tissue.

(3) *Myzus persicae* and *Macrosiphum gei* were found to penetrate by the intracellular method in more than 50 per cent. of the slides examined, and *Myzus circumflexus* in less than 50 per cent. *Macrosiphum gei* showed a higher percentage of phloem penetrations in 1-24 hr. than the other aphides.

(4) There were no visible toxic effects on the part of the host plants to the insects' saliva with either tobacco or sugar beet.

(5) A possible correlation between the behaviour of *Myzus persicae* and M. *circumflexus* with cucumber virus I and localisation of this virus in the leaf is discussed.

(6) Increased infections with increased feeding times on both infected and healthy plants, in the transmission of sugar-beet yellows virus by its vector *M. persicae* is discussed in relation to phloem feeding.

65. SADASIVAN, T. S. 1940. *A quantitative study of the interaction of viruses in plants.* Ann. Appl. Biol., **27**, 359-67.

When the saps of healthy plants are mixed with potato virus " X^s " or aucuba mosaic virus *in vitro* there is an inhibition of the lesion production on *N. tabacum* and *N. sylvestris* leaves. Saps containing unrelated viruses also reduce the infectivity to the same extent as healthy saps. However, saps containing strains of related virus, have a greater and specific inhibitory action. Experiments were performed to show that this specific reduction produced by related strains of viruses is due to the viruses themselves and not other metabolic products present in the saps.

Further study by inoculating related strains of viruses *in vivo* has shown that the local lesions of one strain are inhibited by another when the latter systemically infects hosts, and that the efficiency depends on the concentration of the systemically infecting viruses in such hosts. The degree of inhibition of aucuba mosaic virus is directly proportional to the number of active units of tobacco mosaic virus present in the leaf tissues at the time of reinoculation.

66. SHEFFIELD, F. M. L. 1939. *Some effects of plant virus diseases on the cells of their hosts.* J. Roy. Microsc. Soc., **59**, 149-61.

Some virus diseases cause no apparent abnormalities in the cells of the host plant. Others induce the production of inclusion bodies. These are in some cases amorphous, in others crystalline. The different types of inclusion are described and compared. The nature of intracellular inclusions is discussed briefly in the new light thrown by the recent work on the isolation of plant viruses.

67. Sheffield, F. M. L. 1941. *The cytoplasmic and nuclear inclusions associated with severe etch virus.* J. Roy. Microsc. Soc., **61**, 30-45.

Severe etch virus induces two types of intracellular inclusion.

The cytoplasmic inclusions are amorphous. Chemically they consist of mixtures of proteins with fats and lipoids. They are formed by the aggregation of particles which appear in the streaming cytoplasm.. They may contain some birefringent particles and may give rise to small needle-like bodies. They can be pricked or divided into portions with a microneedle. They contain the virus, but this is also present in other parts of the cell. They are numerous and occur in most tissues of the plant.

The intranuclear inclusions give protein reactions and are more stable than the cytoplasmic inclusions. They take the form of thin rectangular plates, and as many as 30 may be found in a single nucleus. They can be isolated but can be broken or dissolved only with difficulty. Almost every nucleus contains them and they have been found in almost all tissues. They occur in the seed but have not been found in the young embryo. The virus is not transmitted through the seed.

The two types of inclusion are briefly discussed and compared with other inclusions occurring in diseased and healthy tissues.

68. Sheffield, F. M. L. 1942. *Presence of virus in the primordial meristem.* Ann. Appl. Biol., **29**, 16-17.

It was thought that the absence of intracellular inclusions from the apical meristem of infected plants might be due to failure of the virus to penetrate there. However, if this tissue is dissected out from shoots or roots of plants with tobacco or aucuba mosaic, infections can be obtained from it.

69. Sheffield, F. M. L. 1942. *The "blotches" on leaves of Arran Pilot potatoes.* Ann. Appl. Biol., **29**, 341-45.

About flowering time a greyish green blotch appears on some of the leaves of Arran Pilot potato plants. It is due to necrosis of the epidermis, followed by cell division in the palisade tissue resulting in the formation of several layers of small, thin-walled colourless cells. This proliferation may occur on the top only or on both sides of the leaf. The new tissue partially masks the green colour of the plastids in the cells nearer the centre of the leaf. After a few weeks the central tissue dies. The blotching, which is almost certainly of genetic origin, is discussed in comparison with other plant effects which resemble it in one or other of its characters.

70. Sheffield, F. M. L. 1943. *Value of phloem necrosis in the diagnosis of potato leaf-roll.* Ann. Appl. Biol., **30**, 131-36.

In plants infected with leaf-roll virus a type of phloem obliteration and necrosis occurs which is distinct from any abnormality produced by other pathogens or arising from physiological causes. The necrosis occurs in the primary phloem only of the bicollateral bundles. The affected tissue reacts with phloroglucinol in HCl. It was present in all of 179 plants of 33 varieties showing secondary leaf-roll which were examined and was not found in any of 83 healthy plants of 20 varieties. The amount of necrosis varies in different plants. If the disease is severe, necrosis may extend to almost all parts of the plant except the stolon, tubers and roots. If the infection is mild it may be confined to a very few strands in two or three nodes near the base of the main stem. Phloem necrosis can always be found before leaf rolling is apparent.

In primary leaf-roll, slight necrosis can be found in the stem near the bases of the lowest rolled leaves and sometimes in the petioles.

A technique is suggested for the use of this symptom in diagnosis.

71. Watson, M. A. 1940. *Studies on the transmission of sugar beet yellows virus by the aphis,* Myzus persicae (*Sulz*). Proc. Roy. Soc., B, **128**, 535-52.

The efficiency of the vector *Myzus persicae* in transmitting sugar beet yellows virus increased greatly with increasing feeding time on the infected plants. Infection was produced on a succession of healthy plants for 1, 2, or 3 days depending on the length of the infection feeding time. The infectivity of the vectors increased with increasing feeding time on the healthy plants undergoing infection, and decreased with increasing feeding time on healthy

plants prior to those on which the infection trial was made. There was no clearly defined " incubation period " of the virus in the vector, below which no insect could cause infection, but there was variation in the time between cessation of infection feeding of the aphis and the initiation of infection in the healthy plants.

The relations of this virus with its vector differ from those of the viruses already described as *non-persistent* (Watson and Roberts, 1939). For the latter viruses infectivity is lost by *M. persicae* soon after cessation of infection feeding ; after fasting the vectors become optimally infective almost immediately on penetrating infected tissues of the leaf. Their infectivity decreases with increasing feeding time on the infected plants, and increases only slightly with increasing feeding time on the healthy plants.

The behaviour of sugar beet yellows virus is compared with that of curly-top virus of sugar beet, in which infectivity also persists for an indefinite period in the vector and increases with increasing feeding time on infected and healthy plants.

72. Watson, M. A. 1942. *Sugar beet yellows virus. A preliminary account of experiments and observations on its effect in the field.* Ann. Appl. Biol., **29**, 358-65.

The symptoms of sugar beet yellows virus in the field vary with different meteorological and cultural conditions. Illustrations of typical symptoms are given, and some account of their appearance and distribution in the field. Infection greatly reduces the yields of roots and sugar. In experiments early infection on late sown beet caused a loss of 67 per cent. of the root, and 71 per cent. of the sugar yield. The loss decreased with later infection and earlier sowing date. The main source of infection and means by which the virus is carried over from year to year appears to be the sugar beet seed crop. Proximity of the seed crop to the root crop determines the number of viruliferous migrant aphides which enter the root crop at the initial infestation. Subsequent spread of virus in the root crop is determined by the rate of reproduction and of movement of the apterous aphides. Reproduction is more rapid on late than on early sown beet, and seems to be increased by poor nutrition of the plants.

73. Watson, M. A. 1946. *The transmission of beet mosaic and beet yellows viruses by aphides ; a comparative study of a non-persistent and a persistent virus having host plants and vectors in common.* Proc. Roy. Soc., B, **133**, 200-219.

The behaviour of beet mosaic and beet yellows viruses in relation to their insect vectors was compared, using *Myzus persicae* (Sulz.) as the vector and sugar beet as the common host plant. Beet mosaic virus proved to be one of the " non-persistent " group, resembling *Hyocyamus* virus 3, and potato virus Y, etc. Its vectors were optimally infective when allowed to feed for only 2 or 3 minutes on the source of infection after a period of fasting. Feeding time on the healthy plant had only a small and limited effect on infectivity, in some conditions of infectivity of the aphides. The vectors lost infectivity rapidly when feeding and slowly when fasting. When optimally infective they could infect several healthy plants in succession but only during the first half-hour after cessation of infection feeding. When fasting about 25 per cent. of the vectors retained infectivity for 20 hours.

Vectors of beet yellows virus were optimally infective after about 6 hours infection feeding and 3 hours feeding on the healthy plants. They could infect in much shorter time, but their infectivity increased up to about these limits. The efficiency of the vectors was not affected by a period of fasting given before infection feeding. The period of delay in production of optimum infectivity during feeding on the healthy plants was independent of the infection feeding time. Vectors of beet yellows virus lost infectivity more rapidly when fasting than when feeding on healthy plants. There was no increase of infectivity during the first few hours of fasting as there was during feeding, and the curve relating loss of infectivity to fasting time was similar to that obtained with beet mosaic virus.

Aphis fabae (Scop.) behaved similarly to *M. persicae* with both viruses. Differential fasting and feeding treatments were used to separate the viruses when they infected the same plant, and the method could be used for separating complexes which occur in nature and which include non-sap transmissible viruses such as beet yellows virus.

74. WATSON, M. A. and ROBERTS, F. M. 1939. *A comparative study of the transmission of* Hyoscyamus *virus* 3, *potato virus Y and cucumber virus* 1 *by the vectors* Myzus persicae (*Sulz.*), M. circumflexus (*Buckton*), *and* Macrosiphum gei (*Koch*). Proc. Roy. Soc., B, **127**, 543-76.

Three strains of *Hyoscyamus* virus 3, two of cucumber virus 1, and potato virus Y, were tested for their transmissibility by the aphides, *Myzus persicae*, *M. circumflexus*, and *Macrosiphum gei*. The efficiency of the vectors in transmitting all the viruses increased with increasing time of fasting before feeding on the infected plants. Their efficiency decreased as the time of feeding on the infected plants increased. The most probable explanation of these effects is that the viruses are inactivated by some substance produced by the aphides when feeding.

The most successful vector on the whole was *Myzus persicae*, and the least successful was *Macrosiphum gei*, but the relative efficiency of the vectors varied with the different viruses, indicating that their degree of success depended upon several interacting factors. The most important of these factors appeared to be :

(*a*) The concentration of virus in the host plant.
(*b*) The localisation of virus in the host plant.
(*c*) The capacity of the vector for inactivating the virus.

The viruses which have thus been shown to be similar in their insect-virus relationships, are also similar in their physical properties, and there are many other aphid transmitted viruses which resemble them in this respect. It is suggested that such viruses may form a natural group, with the same type of vector-virus relationship. This relationship appears to be a complex one, and it is unlikely that the viruses are mechanically transmitted.

75. WATSON, M. A. and ROBERTS, F. M. 1940. *Evidence against the hypothesis that certain plant viruses are transmitted mechanically by aphides.* Ann. Appl. Biol., **27**, 227-33.

Individuals of *M. persicae*, when given an adequate fasting period followed by 2 minutes feeding on the infected plants, can transmit *Hyoscyamus* 3, potato Y, and severe-etch viruses from tobacco to a number of successive healthy plants. The number of plants infected seems to be that on which the insects can be given 2 minute feeding periods, within the time for which they would normally retain their infectivity if prevented from feeding at all. This is considerably longer than the time for which they would remain infective when feeding on a healthy plant. Rapid loss of infectivity of the vectors, especially when feeding, is a characteristic property of the type of virus used in these experiments which we have defined as " non-persistent " (Watson & Roberts, 1939). The present results confirm our previous hypothesis that loss of infectivity is not due to cleansing of the stylets when feeding, or to normal deterioration of the virus in the insects when fasting. The viruses appear to be inactivated by some substance produced by the aphides after they have been feeding for about 2 minutes. Persistent viruses, which are retained by their vectors for indefinite periods, are not affected by this substance, the vectors being able to acquire lasting infectivity by prolonged feeding upon infected plants, even when the virus available in the leaves is highly localised or very limited in amount. Most of the major differences between the results of transmission experiments with the two types of viruses could be accounted for by differences in the effect of the inactivating substance produced by the vectors. It is therefore unnecessary to postulate fundamentally different mechanisms of transmission between the two types.

MYCOLOGY

BOOK

76. GARRETT, S. D. 1944. *Root disease fungi.* The Chronica Botanica Co., Waltham, Mass., U.S.A., p. 77.

REVIEWS

77. GARRETT, S. D. 1939. *Soil-borne fungi and the control of root disease.* Imp. Bur. Soil Sci. Tech. Comm., **38**, p. 54.

78. Garrett, S. D. 1942. *The take-all disease of cereals.* Imp. Bur. Soil Sci. Tech. Comm., **41**, p. 40.

79. Garrett, S. D. 1945. *The root-infecting fungi.* Endeavour **4**, 104-7.

SCIENTIFIC PAPERS

80. Blair, I. D. 1943. *Behaviour of the fungus* Rhizoctonia solani *Kühn in the soil.* Ann. Appl. Biol., **30**, 118-27.

Rhizoctonia solani was found able to grow as a saprophyte through natural unsterilised soil. Its rate of growth under different soil conditions in glass tumblers was studied by the Rossi-Cholodny soil-plate method. Growth was most rapid at the lowest soil-moisture content tested, viz.: 30 per cent. saturation, and was accelerated by forced aeration of the soil. The maximum distance to which mycelial growth could be supported on the food reserves of the agar inoculum alone was some 5 cm., as shown by extent of growth through tubes of moist sand, but in 23 days the fungus grew 21-24 cm. through tubes of soil. Removal of the agar disk 2 days after inoculation of the tubes reduced growth through sand by more than half, but through soil by only a small proportion. In soil, *Rhizoctonia* was able to cause 100 per cent. damping-off of radish seedlings planted at a radial distance of 4 cm. from the agar inoculum, and some 40 per cent. damping-off at a distance of 9 cm. The depressing effect of additions of 1 per cent. ground-wheat straw or dried grass to the soil upon growth of the fungus was attributed to (*a*) the negligible cellulose-decomposing ability of *Rhizoctonia*; (*b*) nitrogen starvation of the mycelium, through rapid utilisation of the available soil nitrogen by the cellulose-decomposing micro-organisms multiplying upon the fresh organic material; (*c*) fungistatic action on *Rhizoctonia* of the respiratory carbon dioxide produced by the cellulose-decomposers.

81. Buddin, W. and Garrett, S. D. 1944. *Take-all of cereals in* 1943. Agriculture **51**, 108-10.

Quantitative methods used for this take-all survey in the Southern Advisory Province are described, and examples given of the effect of susceptible grass weeds acting as carriers of the take-all fungus.

82. Dion, W. M. and Lord, K. A. 1944. *A comparison of the toxicity of certain dyestuffs to the conidia of* Fusarium culmorum. Ann. Appl. Biol., **31**, 221-31.

The toxicity of a number of dyestuffs to the spores of *Fusarium culmorum* and *Cercosporella herpotrichoides* was determined by the slide-germination technique. No attempt was made to distinguish between fungistatic and fungicidal activity.

The toxicity of basic dyestuffs was unaffected by the acid radicle associated with the dye base.

The high toxicity to *Fusarium culmorum* of malachite green dye base was reduced weight for weight and mole for mole by substitution of ethyl, propyl, or butyl groups for methyl groups.

The reduction of malachite green to malachite green *leuco* base removed toxicity.

The substitution of amino groups and alkylated amino groups in benzene nuclei of triphenyl methane increased toxicity, whereas acid groups reduced toxicity. Sulphonation and carboxylation reduced toxicity to vanishing point.

Alkylation of amino groups increased, but alkylation of benzene nuclei did not affect toxicity appreciably.

When the central carbon atom of the triphenyl methane dyestuffs was replaced by nitrogen (e.g., Bindschedler's green) the diphenyl ammonium compounds were less toxic than the corresponding triphenyl methane compounds.

The prevention of rotation of the aminated benzene rings by bridging, in the O-position to central atom, with O or N, and so obtaining a planar molecule, only slightly affected toxicity.

Certain acid dyes stimulated fungal growth.

The toxicity of the basic dyestuffs seems to depend not on one specific part but on the molecule as a whole, and within certain limits the structure may be varied without pronounced changes in toxicity.

83. GARRETT, S. D. 1940. *Utilisation of nitrogen by* Ophiobolus graminis. Nature, **145**, 108.

A pure culture of *Ophiobolus graminis*, growing on sterilised wheat straw, was found to utilise nitrate nitrogen.

84. GARRETT, S. D. 1940. *Soil conditions and the take-all disease of wheat. V. Further experiments on the survival of* Ophiobolus graminis *in infected wheat stubble buried in the soil.* Ann. Appl. Biol., **27**, 199-204.

Further experiments are reported on the survival of *O. graminis* in infected wheat straw buried in soil. The longevity of the fungus appears to be closely related to the available nitrogen content of the soil. Microscopical observation has shown that the characteristic dark mycelium of *Ophiobolus* slowly continues to develop in the artificially infected straw after this has been buried in the soil. This development of dark mycelium is greater, and also more sustained, in soils well supplied with nitrogen. Additional nitrogen is now considered directly to benefit *Ophiobolus*, by enabling the fungus to assimilate more of the undecomposed carbohydrate reserves of the straw. Conditions such as high aeration favouring general microbiological activity in the soil hasten the disappearance of *Ophiobolus*, probably by promoting a more rapid consumption of the available food material by the fungus itself and by associated micro-organisms ; the supply of nitrogen normally limits both the amount of available food material and the survival of *Ophiobolus*.

85. GARRETT, S. D. 1941. *Soil conditions and the take-all disease of wheat. VI. The effect of plant nutrition upon disease resistance.* Ann. Appl. Biol., **28**, 14-18.

Red Marvel spring wheat plants were grown singly in sand culture in 7 in. glass flower pots under conditions of full nutrient supply, and under deficiencies of nitrogen, phosphate and potash and of all three together, respectively. After one month's growth, the plants were inoculated with *Ophiobolus* by the insertion of two pieces of infected wheat straw into the sand on each side of and just below the crown.

Satisfactory root infection occurred in every plant inoculated, but was lightest in the nitrogen-deficient plants, whilst the potash-deficient plants exhibited a rather more intense root infection than those of any other series. Percentage infection of the stem-bases was lowest in the full nutrient and in the nitrogen-deficient plants, and highest in the series deficient in all three nutrients.

In the uninoculated control plants, a significant depression in grain yield was produced only by the deficiency of phosphate ; in the inoculated plants, however, deficiency in any one of the three plant nutrients significantly reduced grain yield. Infection significantly reduced yield in every series except that receiving full nutrients ; the percentage reduction was greatest in the phosphate-deficient plants.

86. GARRETT, S. D. 1941. *Soil conditions and the take-all disease of wheat. VII. Survival of* Ophiobolus graminis *on the roots of different grasses.* Ann. Appl. Biol., **28**, 325-32.

Sixteen species of grasses were inoculated with *Ophiobolus graminis*, and their roots examined under the binocular dissecting microscope for runner hyphae and discoloured disease lesions. Whilst some species were obviously susceptible and others showed few signs of root infection, there were yet other species which were difficult to classify either as susceptible or as resistant. The effectiveness of these 16 grasses as perpetuators of *Ophiobolus* was therefore directly tested, as follows. The seed was sown in contact with a minimal amount of inoculum in boxes of a light-textured soil ; 2 months after planting, the grass tops were cut off, and the sods inverted in the boxes. The degree of survival of *Ophiobolus* in the inverted sods of the different grasses was determined at approximately monthly intervals by the planting of test wheat seedlings. Whilst all 16 species propagated *Ophiobolus* to some extent, as compared with a negligible survival in fallow soil and under clover, there were notable differences in the longevity of the fungus under different grasses. The resistance of *Phleum pratense*, reported by previous investigators, was confirmed, and seeds mixtures employing this grass and *Avena elatior* in place of *Lolium* spp. were suggested for use on heavily-infected land.

87. GARRETT, S. D. 1944. *Soil conditions and the take-all disease of wheat.* VIII. *Further experiments on the survival of* Ophiobolus graminis *in infected wheat stubble.* Ann. Appl. Biol., **31**, 186-91.

Assimilable nitrogen in various forms prolonged the life of *Ophiobolus graminis* in infected wheat straw, whether added directly to the straw or to the surrounding soil. When the infected straws were buried in washed quartz sand, 0·5 g. nitrogen per 100 g. air-dry straw was the optimum dressing for longevity of *Ophiobolus*. Addition of sodium phosphate did not significantly increase longevity.

Nitrogen is considered to prolong the life of *Ophiobolus* by enabling the mycelium to form new branch hyphae, which can explore unexhausted parts of the substrate ; it is suggested that aged mycelium dies from carbohydrate starvation, through exhaustion of the zones of enzymic erosion around the hyphae. This hypothesis is supported by the extended life of the fungus in infected straws that were shaken twice weekly in 3% dextrose solution.

Ophiobolus was found to survive longer in infected straws buried in a fallow soil than in the same soil under oats, mustard or trefoil ; this finding suggests the use of catch crops as competitors with *Ophiobolus* for soil nitrogen.

88. GARRETT, S. D. and DENNIS, R. W. G. 1943. *Note on the occurrence of* Ophiobolus graminis *Sacc. var.* Avenae *E. M. Turner in Scotland in* 1942. Trans. Brit. Mycol. Soc., **26**, 146-7.

Giving ascospore measurements of *O. graminis* var. *Avenae* from 21 collections of diseased material.

89. GLYNNE, MARY D. 1939. *Eyespot lodging of wheat caused by* Cercosporella herpotrichoides *Fron.* Agric. Prog., **16**.

Paper read before Conference of Advisers, December, 1938.

90. GLYNNE, MARY D. 1942. Cercosporella herpotrichoides *Fron., causing eyespot of wheat in Great Britain.* Ann. Appl. Biol., **29**, 254-64.

Surveys of wheat in 1941 showed that the probability of general lodging in heavy crops is greatly increased when a high percentage of the straws is infected by *Cercosporella herpotrichoides*. Individual straw lodging resulting from infection occurs both in heavy and in light crops, so that the straws fall in all directions. The trouble has been known to farmers for many years under various dialect names, and when severe is estimated to cause a reduction in grain yield of about 30%. A survey of 170 randomly selected fields in sixteen counties showed increases in the frequency and severity of infection by eyespot from west to east, 3·6% of the fields in North Wales showed eyespot and 84·5% in the eastern counties ; the percentage area lodged increased in the same way from 1·1 to 16·4% and the percentage of the area under wheat (in 1939) from 0·17 to 12·89%. Two hundred and thirty-five fields not randomly selected, in three independent surveys, included 118 in which no wheat or barley had been grown in the preceding 4 years ; thirty-seven of these showed eyespot infection, always less than 20% straws being infected ; 115 fields which had wheat or barley recorded at least once in the preceding 4 years, included eighty-nine with eyespot, more than half having over 20% straws infected. Infection of over 20% and over 70% occurred on a few fields in which the last preceding wheat or barley crop had been taken in 1937 or 1938, but they were most frequent where wheat or barley (or one of each) had been grown in at least 2 of the preceding 4 years. The disease is likely to increase in wheat-growing districts under the more intensive wheat cultivation resulting from war-time conditions. Measures for reducing loss from eyespot, while increasing wheat acreage, are discussed.

91. GLYNNE, MARY D. 1942. *Eyespot in wheat.* Agriculture, **49**, 91-94. Giving general field observations and recommendations for control.

92. GLYNNE, MARY D. 1944. *Eyespot,* Cercosporella herpotrichoides *Fron., and lodging of wheat.* Ann. Appl. Biol., **31**, 377-8.

Paper read before Association of Applied Biologists.

93. GLYNNE, MARY D. 1945. *Eyespot of wheat and barley.* Adv. Leafl. Minist. Agric. Fish., **321**.

Giving general field observations and recommendations for control.

94. Glynne, Mary D. 1946. *Eyespot of wheat and barley in Scotland in* 1944. Ann. Appl. Biol., **33**, 35-39.

In August 1944, eyespot (*Cercosporella herpotrichoides* Fron.) was found in 90 out of 121 autumn-sown wheat crops distributed over 12 Scottish counties. It was abundant enough in 40 fields to be likely to harm subsequent crops, and was causing obvious loss in all crops. The disease was found in 17 out of 18 spring-sown barley crops, more than half the straws being infected in 7 of them. About 4 per cent. of the wheat inspected was lodged mostly by eyespot and about 38 per cent. of the barley, mostly non-parasitically. Eyespot increased with the frequency of wheat and barley in the two preceding years, but a few infected crops occurred on fields where no wheat or barley had been grown for many years. In Scotland, where the atmosphere is more humid, eyespot tends to increase more rapidly than in similar rotations in England ; lesions are found higher up the straw and the disease is much more prevalent on spring-sown barley. The long rotations practised in Scotland prevent more extensive damage by eyespot.

95. Glynne, Mary D. and Ritchie, Wendy M. 1943. *Sharp Eyespot of wheat caused by* Corticium (Rhizoctonia) solani. Nature, **152**, 161.

Although one heavily infected crop had been reported, sharp eyespot rarely affected more than 1 per cent. of the straws in the numerous wheat fields of England and Wales in which it had been found. It did not seem to increase with the frequency of wheat and barley in the rotation as did true eyespot, due to *Cercosporella herpotrichoides*.

96. Glynne, Mary D., Dion, W. M. and Weil, J. W. 1945. *The effect of eyespot* (Cercosporella herpotrichoides *Fron.*) *on wheat and the influence of nitrogen on the disease.* Ann. Appl. Biol., **32**, 297-303.

The effect of eyespot throughout the season on wheat receiving different amounts of nitrogen was studied in pot experiments. Plants inoculated in December showed chlorosis of outer leaves in February. Among plants with high nitrogen, eyespot killed 11 per cent., caused straggling of 31 per cent and whiteheads in 14 per cent. of the surviving ear-bearing straws, reduced yield of straw by 8 per cent. and of grain by 16 per cent. The loss in straw yield was due to reduction in plant number, that of grain was about half due to reduction in number of ears and half to production of lighter grains. Among plants with low nitrogen the disease killed 23 per cent. of the plants, caused straggling of 86 per cent. and whiteheads in 18 per cent. of the surviving ear-bearing straws, and reduced yield of straw by 23 per cent. and of grain by 44 per cent. The loss in straw yield was due to death of plants, that of grain was about two-thirds due to the production of fewer ears and one-third to that of lighter grains. In the high-nitrogen series the number of shoots at the time of maximum tillering was reduced by 29 per cent. ; in the low-nitrogen series the disease caused reduction in height, a very uneven crop, delay in ear and anther emergence, and an increase in tail corn from 4 per cent. in the controls to 30 per cent. in the inoculated plants.

All inoculated plants became infected, but those receiving high nitrogen had only 49 per cent. of the ear-bearing straws with severe lesions at harvest, while those receiving low nitrogen had 86 per cent. The larger number of tillers produced when nitrogen was applied probably enabled the less severely diseased shoots to survive and bear ears while the most severely infected died.

97. Gregory, P. H. 1945. *The dispersion of air-borne spores.* Trans. Brit. Myc. Soc., **28**, 26-72.

The deposition of air-borne fungus spores decreases with increasing distance from a source. The factors controlling the scattering are reviewed, and observed gradients of deposition are discussed.

The terminal velocities of spores depend on their dimensions and are of the order expected for smooth, spherical particles from Stoke's law. Fungus spores have been observed to fall with velocities between 0·04 and 2·5 cm. sec., and pollen grains between 1·5 and 40 cm. sec. The mean wind velocity at 10 m. is near 300 cm. sec. Attempts to calculate the dispersal of spores as the result of vertical fall under gravity and horizontal wind movement are shown to apply only to non-turbulent air movement, and therefore to be inapplicable at heights more than a few millimetres above the earth's surface. Differences in rate of spore fall are probably not major factors in dispersal.

It is more appropriate to consider a spore cloud in suspension in the air in process of being diluted by eddies in the course of its transport by the wind.

In support of the concept of the spore cloud as a suspension it is shown that at heights in the atmosphere above the surface layers, the concentrations of pollen and spores decreases exponentially with increasing height in the manner that would be expected if particles falling under gravity were balanced by other particles diffused upwards by eddies. The values for eddy diffusivity, K, varying from $1{\cdot}5 \times 10^4$ to $3{\cdot}3 \times 10^5$, deduced for spores and pollen, are of the order usually found in meteorological work.

While terminal velocity may play only a small part in spore dispersal, it may be more important in causing deposition of spores brought down by eddies to the boundary layer of relatively still air a few centimetres thick at the earth's surface.

The earlier theories of eddy diffusion, including that of Schmidt, are compared with recent work by Sutton who considered that the size of eddies effective in diluting a cloud, instead of remaining constant, increases with the distance travelled by the cloud. Experiments by Stepanov, in which spores were liberated from a point in the open air and trapped at various distances and in different directions, are shown to be in excellent agreement with Sutton's theory, and to lead to almost identical values for the parameters for diffusion and turbulence with those found by Sutton.

Based on Sutton's theory, equations are given for the deposition of spores at various distances from a point source, and from Stepanov's data it is concluded that in travelling across 1 sq. cm. of surface there were deposited the equivalent of the number of spores present in a layer on the axis of the cloud about half a millimetre thick. This value is expressed as a coefficient of deposition, p, and it is regarded as a parameter of considerable biological significance.

The relevance of the deposition formula is discussed. Observed gradients of air-borne plant infections originating from a point source are shown to be closely predicted by this theory. Fungi known or suspected of being splash-dispersed on the contrary show gradients incompatible with the theory. Gradients from strip sources cannot be dealt with satisfactorily at present but an approximate formula is given, and observed gradients from strip sources are found to show reasonable agreement.

The significance for plant hygiene of this interpretation of fungus spore dispersal is that, while attention should be paid to isolation, most emphasis should be placed on eliminating foci of disease within a crop.

98. Moore, F. Joan. 1945. *A comparison of* Fusarium avenaceum *and* Fusarium caeruleum *as causes of wastage in stored potato tubers.* Ann. Appl. Biol., **32,** 304-09.

Fusarium avenaceum is reported for the first time as a cause of rotting of potato tubers in Britain. The progress of rotting in tubers infected with *F. avenaceum* has been compared with dry rot due to *F. caeruleum* in the laboratory, clamp and potato store. Of the four varieties, Majestic, King Edward, Doon Star and Arran Pilot, tested for susceptibility, King Edward was the most susceptible to *F. avenaceum* and Doon Star to *F. caeruleum.*

Optimum temperatures for growth on potato-dextrose agar were 20-25° C. for *F. avenaceum* and 20° C. for *F. caeruleum* ; maximum temperatures were >30° and 30° C. respectively. For infection of wounded potato tubers, cardinal temperatures for *F. avenaceum* were similar to those on agar, but for *F. caeruleum* the optimum was 15° C. and the maximum 25° C. The optimum temperature for rotting tended, with both species, to be higher in the more susceptible potato varieties. At low temperatures *F. caeruleum* caused quicker rotting than did *F. avenaceum,* even though its rate of growth on agar was scarcely more than half that of the latter.

High humidity favoured rotting especially by *F. avenaceum ; F. caeruleum* was more tolerant of relatively low humidity. Both species caused quicker rotting in the clamp than in store, even though there was no appreciable difference in mean temperature between the clamp and the store. This was attributed to the higher atmospheric humidity in the clamp.

99. ROBERTS, F. M. 1943. *Factors influencing infection of the tomato by* Verticillium albo-atrum. Ann. Appl. Biol., **30**, 327-31.

Infection of tomato plants by *Verticillium albo-atrum* was encouraged by application of nitrogenous manures. Application of phosphate had no significant effect on the progress of the disease, but a deficiency of potash tended to encourage it. Steam-sterilized soil inoculated with *Verticillium* immediately after treatment produced a very high total of infected plants. When inoculation of the steamed soil by *Verticillium* was delayed for 17 days or longer after steaming, the steamed soil was no more favourable for development of the disease than untreated soil. Spread of *Verticillium* from the roots of an infected plant to those of neighbouring healthy plants was hastened by killing the infected plant.

100. ROBERTS, F. M. 1944. *Factors influencing infection of the tomato by* Verticillium albo-atrum. II. Ann. Appl. Biol., **31**, 191-3.

Tomato plants receiving adequate supplies of mineral nutrient acquired great resistance to infection by *Verticillium albo-atrum* if the leaf-shoot ratio was reduced ; this effect is attributed to reduction in carbohydrate content of the host. Wide variation in potash manuring did not affect susceptibility of tomatoes to *Verticillium*.

101. SADASIVAN, T. S. 1939. *Succession of fungi decomposing wheat straw in different soils, with special reference to* Fusarium culmorum. Ann. Appl. Biol., **26**, 497-508.

A study has been made of the sequence of fungi developing on wheat straw buried in four arable soils, an allotment soil, and a glasshouse compost. Both natural untreated straw, and straw autoclaved in a 2 per cent. solution of sodium nitrate were employed. *Fusarium culmorum* and *Mucor* spp. appeared to be dominant organisms in the earlier stages of straw colonization, but these were replaced by *Penicillium* spp. in the latter stages of decomposition. The nitrogenous treatment of the straw favoured the development of *Penicillium* spp. at the expense of *Fusarium culmorum* and *Mucor* spp. The pathogenicity of the *Fusarium culmorum* isolates to wheat seedlings was established by inoculation experiments.

The data provided by this investigation are considered sufficient to justify the inclusion of *F. culmorum* in Reinking & Manns' (1933) group of *soil-inhabiting Fusaria*, or true soil fungi.

102. SAMUEL, G. and GARRETT, S. D. 1945. *The infected root-hair count for estimating the activity of* Plasmodiophora brassicae *Woron. in the soil.* Ann. Appl. Biol., **32**, 96-101.

A method is described for estimating the relative numbers of *Plasmodiophora brassicae* spores germinating in different soils, by counting infected root hairs. Cabbage seedlings are grown for 1 week at 25° C. in glass tumblers of the infected soils ; after washing out, the tap roots are stained in 1 per cent. aceto-carmine and a count is made of the number of root hairs containing zoosporangia of *P. brassicae*, along 2 cm. of root. It is shown that by this method it is possible to study, for example, the action of different bases in inhibiting root-hair infection ; the main inhibiting factor was found to be soil alkalinity, however produced. Other factors were found to influence infection in lesser degree ; thus the number of infected root hairs was reduced in soils receiving N/10 sodium and potassium chlorides in place of distilled water. Root-hair infection was also inhibited by low soil-moisture content.

103. SHEN, C. I. 1940. *Soil conditions and the* Fusarium culmorum *seedling blight of wheat.* Ann. Appl. Biol., **27**, 323-29.

The influence of soil conditions upon the *Fusarium culmorum* seedling blight of wheat has been studied by means of the glass tumbler technique. Intensity of infection increased with density of the spore suspension used to inoculate the seed, but was reduced by germinating the seed for 48 hrs. or more before inoculation. Infection was most severe at a low soil moisture content and in acid soil. In nutrient sand culture, infection was highest in

the no-nutrient series and lowest in that receiving full nutrients. Nitrogen alone appeared to be as effective in reducing infection as the full nutrient solution, phosphorus was less effective, whilst potassium had no beneficial effect at all upon seedling resistance.

104. Turner, E. M. 1940. Ophiobolus graminis *Sacc. var.* Avenae *var. N., as the cause of take-all or whiteheads of oats in Wales.* Trans. Brit. Mycol. Soc., **24**, 269-81.

Outbreaks of take-all in oats have often been reported in recent years from Wales, and occasionally from Australia, Denmark and Holland, although in most parts of the world it is commonly held that oats resist the disease. Isolates of *Ophiobolus* from oats grown in Wales were indistinguishable in cultural behaviour from *O. graminis*, but they were very pathogenic to oats, which were found to be highly resistant to ordinary *O. graminis*.

The histology of the infection of oat plants by the fungus from Wales and by *O. graminis* was studied in detail. It was found that there were significant differences between the two groups of isolates in the length and septation of the ascospores, the Welsh material giving a length of 101-117μ, the English material 79-86μ.

The fungus from Welsh oats is therefore regarded as a new variety *Ophiobolus graminis* Sacc. var. *Avenae* E. M. Turner.

105. Walker, A. G. 1941. *The colonization of buried wheat straw by soil fungi, with special reference to* Fusarium culmorum. Ann. Appl. Biol., **28**, 333-50.

A study has been made by Sadasivan's (1939) technique of the colonization by fungi of wheat straw buried in the soil. One-inch lengths of sterilized straw were buried in the experimental soils in 3½-in. flower pots; after incubation at laboratory temperature (16-20° C.) for the required period the straws were washed out of the soil, surface sterilized by mercuric chloride or other sterilizing agent and plated out on acidified potato-dextrose agar (pH 5·0).

Fusarium culmorum and *Penicillium* spp. were numerically the most important organisms developing from the straws on the plates, at least during the first 5 months of incubation in the soil. Both groups of organisms, together with others, appeared generally to be present in the decomposing straw, but the method of surface sterilization employed apparently decided which organism produced a colony on the isolation plate.

Fusarium culmorum, a fungus of a vigorous and rapid habit of growth, showed low resistance to the action of the more severe sterilizing agents, such as mercuric chloride and silver nitrate, but developed better after surface sterilization of the straws with calcium hypochlorite, a mild sterilizing agent, and best of all after a mere washing in sterile water. *Penicillium* spp. were apparently crowded out by the more vigorous growth of *Fusarium culmorum* after these mild treatments of the straws; on the other hand, they were very tolerant of the more severe surface sterilizing agents, mercuric chloride and silver nitrate, and after the longer period of treatment were often the only organisms developing on the plates.

The pathogenicity to wheat seedlings of the isolates of *F. culmorum* obtained from decomposing wheat straw was shown to be comparable with that of isolates of the same fungus secured from diseased cereal plants.

SECTION OF BIOCHEMISTRY

By N. W. Pirie

No formal biochemical work was being carried out in Rothamsted at the beginning of 1940, but in the autumn of that year two independent biochemical laboratories were started. In October N. W. Pirie was appointed Virus Physiologist on the understanding that this title was to be interpreted practically as Biochemist, and a little later an A.R.C. unit under J. H. Quastel was set up, but has now been transferred elsewhere. The Biochemistry Section was an offshoot of the Plant Pathology Department, but as the scope of the work is being extended it has now become separate.

In 1941 E. M. Crook came on an A.R.C. grant to investigate the conditions governing the release of protein from the normal leaf. With the arrival of the electron microscope he has been more and more fully occupied with this and has now been transferred to the staff of the Plant Pathology Department. M. Holden came in 1944 and M. V. Tracey in 1945 both on A.R.C. grants to study changes that take place in normal or virus-infected leaves during the operations used in the extraction of viruses. During the second half of 1945 M. Grégoire was working here on a fellowship from the French National Centre for Scientific Research.

All the work on the extraction and fractionation of tobacco-mosaic, tomato bushy-stunt and the tobacco-necrosis viruses was carried out in this laboratory, but having been described in another section need not be set out again.

The conditions governing the release of normal protein from the leaf fibre have been studied in some detail on tobacco and more superficially on some other leaves. Fine grinding, especially in the absence of salts and under slightly alkaline conditions, leads to the separation of nearly all the protein in a soluble form. Much of this is associated with chlorophyll and lipids and is macromolecular, that is to say it can be sedimented in fields of 15,000 R.C.F. though not in fields below 2,000 R.C.F. As the work has proceeded it has become clear that fine grinding is not a simple process of dispersion, but leads also to the condensation of proteins and other leaf components. This makes the interpretation of some results both on normal leaves and on virus-infected ones doubtful. Enzymic methods of disintegration have been sought and considerable success has been achieved with the digestive fluid from snails.

It is to be expected that after maceration many leaf enzymes will be able to attack their naturally occurring substrates. The liberation of viruses on mincing the leaf may not therefore always be a purely mechanical matter, but may be associated with these enzyme actions. The demethylation of pectin has been studied, not because there is any reason to associate it with virus liberation, but because no rigid control of the pH of a leaf suspension is possible until this action has been either inhibited or allowed to go to completion. At pH 6, the normal pH of tobacco, demethylation proceeds slowly, but on raising the pH to 7 or 8 there is a very

great increase in the rate. This is due partly to the greater activity of the enzyme at the higher pHs and partly to the enzyme being released from the fibre in alkaline solution so that enzyme and substrate are more accessible to one another. In some leaves, notably those of the Cucurbitaceae, the sap is already sufficiently alkaline for enzymic demethylation to occur spontaneously. In these leaves also, the pH rises as successive aqueous extracts of the fibre are made. The high pH is due to the presence of calcium ions in the extracts uncompensated by an anion, and in a solution sufficiently free from other buffering material, the fourth or fifth extract for example, the pH may rise to 10. No fully satisfactory picture has yet been achieved of the mechanism of this action but some more or less plausible model systems have been made and work on its interpretation is proceeding. There are marked differences between plant species both in the total amount of pectase present and in the distribution of the enzyme between the fluids and the structure of the leaf. A few experiments have shown comparable differences between leaves of the same species grown under different manurial conditions. It would seem therefore that biochemical data compiled from plants gathered in a rather casual manner, for example in hedgerows, may be extremely misleading and that conclusions should only be based on extensive series of plants grown under a range of manurial and cultural conditions.

Plant proteases are well known, but they are generally derived either from a seed or a latex, inconclusive evidence for the presence of proteases in non-lactiferous leaves has been published. The matter is of importance because, although most plant viruses are completely resistant to attack by the usual proteases when in the native state, some are susceptible to proteolysis. Furthermore the low apparent protease activity of a system that is capable of such active nitrogen metabolism as the leaf is a matter for surprise. The unequivocal demonstration of a protease in tobacco sap is also important because of the claim that tobacco-mosaic virus has protease activity. Since the purified virus is known to combine with proteases a demonstration that healthy tobacco sap contains protease robs the claim of its validity. Trustworthy methods for the detection of dilute protease solutions have been developed, and these show that normal tobacco sap has an activity similar to that of a 0.03 gram-per-litre solution of trypsin. 75 per cent. of the enzyme that has been recognised is in the sap and it can be concentrated by precipitation with ammonium sulphate. The high dilution of the original extract and the instability of the enzyme make it unprofitable to attempt rigorous purification. The protease is not naturally fully active and a 10-fold activation is possible with reducing agents: when activated, the amount of enzyme present in the leaf is sufficient to hydrolyse 10 per cent. of the leaf protein every 24 hours. Protease activity, like pectase activity, depends on the manurial and cultural antecedents of the plant.

In 1939 work that had already been done on the antigens of *Brucella melitensis* was extended to *Br. abortus* in the hope that products with diagnostic and immunising properties could be prepared. By the autumn of 1940 the results were sufficiently

encouraging to justify the transfer of the work to Rothamsted: it is not of course proposed that the study of an organism causing an animal disease should be a permanent feature of work in this laboratory. The fundamental hypothesis is that immunising potency depends on the size of the antigen with which an animal's protective mechanism is confronted, for foreign materials of different sizes and stabilities are dealt with by different mechanisms and not all these lead to immunity. This assumption has been borne out and fractions have been made causing a high degree of immunity in guinea-pigs. Tests on heifers are now in progress. All the animal testing has been done at Cambridge, Weybridge or Compton. The most effective antigen has a particle rather larger than those of the plant viruses studied here and it is a complex of at least two phospholipids with the N-formyl derivative of an amino-polysaccharide.

PUBLICATIONS

1. Holden, Margaret. 1945. *Acid-producing mechanisms in minced leaves.* Biochem. J., **39**,, 172-178.

The drift of pH towards the acid side observed when minced tobacco leaves are neutralised with alkali is mainly due to the enzymic demethylation of pectin when the pH is raised above that of the normal sap. The metabolic production of carbon dioxide is also in part responsible for the drift.

The liberation of methanol is more rapid in milled than in minced leaf fibre, and at pH 8 more rapid than at pH 6, whether in the presence or absence of sap.

Heating to 100°C. prevents the pH drift, and the small amount of methanol liberated at pH 8 is due to non-emzymic demethylation.

The pectase is extracted from fibre at pH 8 but not at pH 6. The pH 8 extract will demethylate boiled fibre and extract pectin.

Minced leaves of some Cucurbitaceae have a spontaneous alkaline drift when washed, which permits demethylation without the addition of alkali.

An improved method for the estimation of methanol is described.

2. Holden, Margaret. *Studies on pectase.* Biochem. J. In the press.

3. Crook, E. M. *Extraction of nitrogen from green leaves.* Biochem. J. In the press.

4. Pirie, N. W. *The manometric determination of formic acid.* Biochem. J. In the press.

DEPARTMENT OF ENTOMOLOGY
1937 - 1945

By C. B. Williams

A summary of the work of the Department of Entomology from its commencement in 1915 to the end of the year 1936 was published in the Annual Report of the Experimental Station for 1936, pp. 99-120. This present Report is, therefore, extended to include the two pre-war years 1937-38 so that it will join on to the previous one and the two will give a complete outline of the work of the Department since its inception.

Since the last Report there has been no change in the senior staff, which consists of C. B. Williams (Head of Department), H. F. Barnes and A. C. Evans.

Temporary workers at the Laboratory during the period include the following ;

W. R. S. Ladell	Soil Insects	1935-38
K. D. Baweja	Soil Insects	1935-37
K. J. Grant	Insect Migration	1935-38
B. Lovibond	Leatherjackets	1935-39
D. C. Thomas	Hemiptera	1937-38
K. N. Trehan	Aleurodidae	1936-38
A. G. Robertson	Tipulidae in Light Trap and Chemotropic responses of Insects	1936-37
J. Deal	Preferred Temperatures of Insects	1936-40
G. F. Cockbill	Insect Migration	1938-41
S. R. Nutman	Collembola and Flea-beetles	1941-43

The Degree of Ph.D. at the London University for work done at Rothamsted was obtained by Baweja, Trehan, Deal and Cockbill.

Miss Lovibond after the first year was appointed to the staff of St. Ives Golf Green Research Station and seconded here to continue her work.

G. F. Cockbill was appointed for two years under a grant obtained from the Leverhulme Foundation for the study of insect migration.

C. B. Williams represented the Department at the Seventh International Congress of Entomology at Berlin in 1938. He also made an extended tour of South America at the invitation of the British Council from September, 1943 to April, 1944 for lecturing and liaison work on entomology and agricultural science. Nearly all the countries of South America were visited, and a number of lectures given including several on the history of Rothamsted. Since his return a steady flow of correspondence has developed putting workers in South America in touch with workers in this country.

Soil insects

An intensive study on the rate of recolonisation of sterilised soil was carried out on an area of allotment soil (36). The soil was sterilised by baking at a temperature of 212° F., for 6 hours. Steri-

lisation was carried out at two dates, in February and in May, and control plots of unsterilised soil were included. One half of the total number of plots were enclosed by iron sheets fixed 1 ft. below the ground and extending 6 inches above the surface. Grass was sown on all the plots. The observations on recolonisation were carried out for a period of just over one year; soil samples 3 inches by 4 inches in area and 9 inches deep were taken and the fauna extracted by the Ladell flotation process, previously developed in the department. The populations were recorded in millions per acre and calculated from the numbers of soil organisms in the sample by the formula (35)

$$\frac{x}{2} + \frac{x - 20}{20}$$

The total population in all the control plots was low during the winter, increased slowly with the advent of warmer weather until the middle of September when there was a rapid increase, the maximum population being reached by about the middle of November. This rapid increase was chiefly due to the increase in the population of Collembola whose activity seems to reach a maximum during a falling range of soil temperature of 55-45° F.

Recolonisation in both cases of sterilisation was very rapid and was rather more rapid in the enclosed plots. By the end of September the populations of the sterilised plots were equal to those of the control plots and at the end of the observations were three to five times as great. The fact that recolonisation averaged five months in the enclosed plots and seven months in the unenclosed plots suggests that there was but little lateral movement in the soil of the soil fauna and recolonisation was mainly effected by surface or aerial movement.

The results of this investigation show that sterilised soil is particularly favourable for the rapid increase of certain insects and that some of these are common glasshouse pests.

Wireworms

Soil insecticides.—One of the major activities of the department has been the study of wireworms, a pest which assumed great importance on the ploughing up of much grassland just before and during the first few years of the war. The first problem studied was the distribution of wireworms in the field and development of an adequate experimental field technique to test chemical control measures (54). Preliminary sampling showed that the distribution of wireworms was very uneven and that the experimental design used, a Latin square, nearly doubled the accuracy of the results. The sampling errors in the three experiments carried out were high, 20-50 per cent. of the mean, and accounted for a high proportion of the experimental error, 20-60 per cent. Several of the soil insecticides used caused a significant decrease in the wireworm population but some unfortunately also had an adverse effect on the crop. Naphthalene at 10 cwt. per acre produced a kill of 60 per cent. No differential action of the insecticides on wireworms of different sizes was found.

A further experiment (49) was carried out to see whether an increased rate of application of naphthalene, 15 cwt. per acre,

would produce a complete kill of wireworms but unfortunately the treated plots did not show any reduction in numbers compared with the control plots. The only reason suggested for the failure of the naphthalene in this experiment is that the application was made in February at a time when wireworms are not usually considered active, whereas in the previous experiment the insecticide was applied in April.

In view of the low return of information relative to the amount of time and labour spent on large-field trials, it was decided to develop a laboratory technique to test new and more promising soil insecticides. Further, the interpretation of the results of the field trials was rendered more difficult by quite large changes in the populations on the control plots, the reasons for which were unknown. Work on the biology of wireworms was therefore begun.

A suitable laboratory technique for testing soil insecticides was developed and a wide range of substances tested. Even in these rigorously controlled experiments there was great variation between replicates carried out at the same time and at different times, pointing to necessity of further reasearch on the wireworm itself. Experiments were carried out on the placing of soil insecticides and fertilisers near the seed.

Biology.—In an oviposition preference experiment it was found that *Agriotes obscurus* L. females laid significantly more eggs in grass and significantly fewer eggs in fallow than in clover, wheat and kale. Marked beetles of *A. sputator* L. were trapped up to 30 yards away from their point of liberation. The ratios of adult *A. obscurus* to *A. sputator* were found to vary greatly from field to field (50).

Owing to the long life of the wireworm it has not yet been possible to study the effect of various factors on growth and mortality over the whole life-cycle but sufficient work has been carried out to provide an adequate basis for such a study (45), (46), (47). It has been found that the number of moults per annum varies inversely with the age of the wireworm and that during the moulting process the wireworm undergoes a considerable increase in weight followed by a decrease in weight. The magnitudes of these changes (in water content only) are such as to vitiate the results of growth experiments unless the experiments are planned so as to take account of them. The type of plant on which the wireworm feeds has a considerable effect on its rate of growth, some plants being very suitable, others less suitable, while flax proved to be very unsuitable for growth. Thus it might be expected that the type of crop grown in any one year might influence the behaviour of wireworms towards the succeeding crop. This conclusion was borne out by the results of an experiment on the cropping of newly ploughed grassland in which eight crops were sown during the first year followed by spring oats. A fairly uniform distribution of wireworms was present during both years, except in the case of one crop mentioned below, but the yields of the cereal crop following the various previous crops differed greatly. In the laboratory experiments, beans proved to be a rather unsuitable food and consequently rather heavy damage was expected to the following oat crops. Contrary to expectations an excellent crop was obtained. The reason for this exceptional result was found to lie in a great reduction of the wireworm

population in the plots which previously carried beans, a reduction amounting to 75 per cent. of the original population. A toxic effect by the roots of the bean plant may be the explanation of this reduction.

The seasonal activity of wireworms is governed by soil temperature and moisture and also their moulting frequency, so that the amount of damage to be expected can depend on several factors, namely, soil conditions both physical and chemical, previous cropping and the frequency of the different size groups in the wireworm population.

The cuticle of wireworms is permeable to water and it has been found that in its relations to soil moisture the wireworm may be regarded as an osmotic system. The pF scale of soil moisture was shown to be a better expression of soil moisture in relation to wireworms than the percentage moisture present.

Leatherjackets

Miss B. J. Lovibond, appointed as Entomologist to the Board of Greenkeeping Research, St. Ives Research Station, Bingley, was seconded to work at Rothamsted following some preliminary investigations carried out by a member of this department. During her stay here (1936-39) she investigated the most important craneflies and their larvae (56) and conducted breeding and sampling experiments (57).

The orthodichlorobenzene emulsion method has also been investigated as a possible means of conducting a long-term study of fluctuations in the abundance of the common leatherjacket (19).

Slugs

This is a case where an immediate problem has developed of necessity into a fundamental one. At the outbreak of the war it was realised that if possible a substitute should be found for bran, a feeding stuff of value, in the metaldehyde-bran method of baiting slugs. Experiments quickly showed, however, that slugs, under the conditions of the experiments which were carried out in gardens, definitely preferred attractant substances of food value. In fact, the better the feeding value of the attractant the more slugs were attracted to and killed by the poison bait (16, 21, 22).

Lack of detailed knowledge concerning the bionomics of slugs leading to difficulties in the complete interpretation of the results of the baiting experiments revealed the necessity of an intensive ecological study.

It was decided to study the slugs in gardens since more species were to be found in gardens than in fields, and eventually about 50 gardens were involved in the investigation. A sampling method is used which consists of picking up all the slugs seen during 30 minutes, during which period the different ecological sites in the garden are visited. This method has shown that enormous numbers are often present, up to 570 slugs being gathered in half-an-hour, followed on one occasion by a further 517 half-an-hour later.

Each species has its own season of abundance during the year. Thus *Arion ater* is most abundant in January, *A. subfuscus* about June, *Agriolimax reticulatus* about July-September, *Milax sowerbyi*

in September and October, *M. gracilis* about October, and *A. hortensis* slightly later in the year.

The study has already shown by observation of the slugs' food habits that slugs are practically omnivorous and that usually in gardens they are scavengers more than pests. It is estimated that 90 per cent. of their food is what the grower does not want either for its aesthetic value or its importance as food.

The distribution of the various species of slugs in neighbouring gardens is most interesting. In the case of two species *A. hortensis* and *M. gracilis* the numbers increase regularly from garden to garden up one side of an old river-bed whereas those of *M. sowerbyi* show a definite ridge of abundance a little way up the slope. The distribution of *A. ater* seems to be associated with the age of the gardens whereas that of *A. reticulatus* seems to be uniformly high whatever the garden. The distribution of *A. subfuscus* is peculiar, this species being abundant almost everywhere on the west side of the old river-bed and almost absent on the other.

The mating season of the two species which mate in the open has been studied, as well as the seasonal weights of the samples of the slugs collected.

Water-colour paintings of the various species have most generously been made by Miss Evelyn Tuke and they are being used, as three plates in the account of this ecological study of slugs in gardens (1, 2, 29, 33, 34).

A further development of this study has been the weighing of the specimens individually. The weights of two species, *A. subfuscus* and *A. reticulatus*, have been thus recorded since July, 1944 and those of one other species, *M. gracilis*, since October, 1944 and those of three other species since the summer of 1945. By this means it is possible to follow the changes in the weight distributions of the active slugs throughout the season and on occasion the growth rate and death rate. This is being linked up with the seasonal weights of populations in neighbouring gardens as well as the weights at which breeding takes place.

The determination of the numerical abundance of active slugs has now continued for four years and gives every promise as a method of investigating the year-to-year abundance of the various species.

Earthworms

Although earthworms are very common in many parts of the world and numerous statements have been made as to the part they play in maintaining soil fertility and soil structure very little indeed is known of their biology, and the results of the little experimental work which has been carried out on their relation to soil fertility are largely valueless owing to this lack of knowledge. In August, 1944 research was begun on earthworms as part of a wider programme on the relationships between the soil fauna and the soil with particular reference to soil fertility.

The relative abundance of the different species on various parts of the Rothamsted Farm and certain other soil types was first studied to decide which species should be used for experimental work. It was found that the proportions of the different species varied greatly according to the previous history of the fields and

on the different soil types. Only the most general statements are available as to the length of the life-cycle of the various species, so cultures of twelve species have been set up to obtain material for a study of this problem. These cultures have also yielded valuable data as to the relative metabolic activity of the different species. On a basis of the weight of cocoons produced during a given time, the larger species have a much lower rate of metabolic activity than the smaller species with one exception *Lumbricus rubellus* Hoffm. a fairly large worm with a high rate of metabolism.

Methods have been developed to study the seasonal activity of worms under laboratory and field conditions, namely ;

(*a*) The rate of deposition of cocoons (i.e., eggs) under known conditions of temperature and moisture.
(*b*) The collection of worm casts at four-day intervals throughout the year.
(*c*) The numbers of earthworms brought to the surface of grassland by watering with a worm irritant.

Weekly estimations, at least, of the soil moisture at three different depths are being made and continuous records of soil temperature at five different depths are available to study the effect of these factors on activity.

The preliminary results of the survey on the relative abundance of the different species shows that *Allolobophora caliginosa* Sav., a large earthworm, was one of the commonest species present on the farm, so it was chosen for the first pot experiment on the effect of earthworms on soil fertility. No data existed on the amount of organic matter which earthworms consume in a given time so a 3 by 3 factorial experiment was set up ; 3 levels of organic matter (bullock droppings) 0, 25 and 50 grams : and 3 worm treatments, 0, 12-13 grams of living worms and 12-13 grams of dead worms. This weight of worms per pot is approximately equal to the amount present in a good pasture. After the worms had acted on the organic matter for 3½ months they were removed and any pots in which more than one worm had died were rejected. Finally five replicates of each treatment were set up and spinach beet sown. The results of the experiments showed that dead worms had a highly significant effect in increasing the yield of spinach but that living worms had no significant effects.

During the course of the above experiment, the biological studies showed that *A. caliginosa* was a worm with a low rate of metabolic activity. In a subsequent experiment, *L. rubellus* a fairly large worm but with a higher rate of metabolism was used as the test subject and the results of the experiment show clearly that it has had a highly significant effect in increasing the yield of the test crop grown, i.e., mustard. Further work along these lines is planned.

Insect physiology

A study of the temperature preferendum of a wide range of insects was carried out (37). The results show that in general a range of temperatures rather than one particular temperature is preferred. The only preference which some insects may be said to show is an avoidance of both extremes of temperature, while some others merely avoid high temperature. Another rather peculiar preference is

presented in the bi-modal curve with a peak near each end of the gradient. In general the preferences of the immature forms tended to coincide with those of the adults of the same species.

A study of the distribution of nitrogen in the castes of the wasp, *Vespula germanica* (Fab.) showed that in the adults most of the nitrogen is present in the cuticular and water-soluble protein fractions, in prepupae, little is found in the cuticle, but over 60 per cent. is in the form of soluble protein. Just emerged wasps probably contain a reserve protein, insoluble in water, which is utilised to complete the hardening of the skeleton. About 60 per cent. by weight of the cuticle and 55-70 per cent. of the total nitrogen is lost when adult cuticle is boiled in 1 per cent. KOH, a method used by previous workers to estimate the weight of cuticle present in an insect (38).

Further examination showed that the cuticle of the mealworm *Tenebrio molitor* L. contains about 60 per cent. of a protein which is easily soluble in water, dilute acids and alkalis. Previous to moulting about 80-85 per cent. of the cuticle is absorbed. The hypothesis is put forward that, in this insect, the material absorbed from the cuticle at the last larval moult may eventually be utilised to form the major part of the adult cuticle (40).

Very little indeed is known how the varying chemical composition of plants at different times of the year, under different manurial conditions, etc., can affect the growth and reproduction of insects, or whether the feeding processes of sucking insects can affect the chemical composition of plants. The cabbage aphis *Brevicoryne brassicae* L. fed on cabbages grown under different environmental conditions proved a very useful subject for this type of work. It was found in a series of cabbages grown under normal conditions of light that the rate of reproduction was positively correlated with the nitrogen content of the host plants and, in particular, with the protein content. In a series of plants grown under subnormal conditions of light the rate of reproduction was positively correlated with the soluble-sugar content and the total water-soluble carbohydrate content of the plant. Thus from November to February, the rate of reproduction is probably dependent on the carbohydrate content of the plant and for the rest of the year on the protein content. A low carbohydrate content in the food of the caterpillar of *Pieris brassicae* L. brings about a slower rate of growth and smaller pupae. It is generally agreed that overcrowding brings about the formation of winged forms in aphids, and there are about as many suggestions as to the cause of this as there have been workers. In the case of *B. brassicae* it has been found that once the protein content of the host plant falls below a critical level there is a highly significant negative correlation between the protein content and the percentage of winged forms present (39).

In addition to the direct reduction of crop yields, insects may also be the cause of changes in chemical composition, a factor likely to be of particular importance in crops, such as sugar beet, grown as a source of special substances. It was found that increasingly high populations of *B. brassicae* brought about a gradual diminution in the fresh-weight yield of cabbages, but that on a dry-weight basis a low population density caused a rapid diminution in yield. This diminution of yield was principally brought about by

a very great decrease in the amounts of reducing sugars, sucrose, starch and acid-hydrolysable substances. Data were also obtained on the effect of the bean aphis *Aphis fabae* Scop. on the composition of field beans, but in this case no significant differences were found between beans obtained from clean or heavily infested plants (44).

Since aphids normally feed on the contents of the phloem tubes it is not possible to study the chemical composition of their food. In the case of lepidopterous larvae this is possible and detailed studies of the utilisation of food have been carried out on four lepidopterous larvae and on one coleopterous larva (41, 42, 43). A technique was developed to determine accurately the amount of food consumed and the weight of excreta derived from it, and chemical analysis was carried out on both food and excreta. In the case of nearly full-grown larvae of the Buff-tip, *Phalera bucephala* L. it was found that 60 per cent. of the water, 60 per cent. of the protein, 80 per cent. of the soluble sugars, 60 per cent. of the fat and 35 per cent. of the ash present in the food were utilised. Polysaccharides were not utilised. Nitrogen was excreted as ammonia and uric acid.

During the period of growth of the larvae, the coefficient of utilisation of dry matter remained approximately constant, but the coefficient of utilisation of water was very high during the first instar, approximately 0.95, and fell to approximately 0.6-0.7 during the second-fifth instars.

$$\text{Coefficient of utilisation} = \frac{\text{Weight utilised}}{\text{Weight consumed}}$$

The amounts of the various chemical substances present in the food are utilised in very different proportions by larvae of different species. Thus the larvae of *Malacosoma neustria* L. utilise starch but hardly any fat, while those of *Aglais urticae* L., *Pieris brassicae* L. and *Phalera bucephala* L. do not utilise starch but do utilise considerable amounts of fat. The amounts of protein utilised by these species also differ. The nutritive ratios of the four species vary from 0.32 to 1.18, and these in turn differ greatly from those of herbivores, 4.7-7.0.

The larvae of *Tenebrio molitor* L. feeding on bran utilise a wide variety of carbohydrates and maintain their water content above that of the food by the retention of metabolic water derived from the oxidation of these carbohydrates. Gliadin, glutenin and K_2SO_4-soluble proteins are utilised.

Relations of insects to climate and weather conditions

In the previous summary of work up to 1936 it was shown how the result of several years' continuous trapping with a light trap was being used as a basis for a statistical study of the relation of weather conditions to insect numbers and insect activity.

The trapping was carried on for four years, and the analysis of the figures continued and published in two papers: the first (71) contains a general account of the different groups of insects obtained in the trap and the different species in the case of Lepidoptera; also an account of the sex ratios in different groups and the factors affecting it; a discussion of the variability in dates of appearance (phenology) in different years; and further data on the time of flight of different insects during the night.

The second paper (75) is a statistical analysis of the numbers caught in relation to weather conditions. In the first place it was shown that much more consistent results could be obtained in statistical analyses by using the logarithm of the number of insects caught instead of the actual number. This means that comparison is most profitable between geometric, rather than arithmetic, changes. Regressions were calculated between the log. number of insects and the various weather factors, such as minimum and maximum temperature, wind, humidity, rainfall, cloud and moonlight. Of these, the minimum temperature was found to be the most important. A rise in the minimum temperature of about 5° F. doubled the catch, and a fall of a similar amount halved it. This effect was approximately the same in summer and in winter, and with different groups of insects. Simultaneous regressions with several factors were also calculated and it was found possible to account for about 60 per cent. of the total variation in insect numbers by known climatic factors.

Finally, an attempt was made to forecast the average level of abundance of all insects during each month, from the rainfall and minimum temperature of the three previous months. Multiple regressions were calculated between the average monthly catch, corrected for activity, and the rainfall and temperature of the three previous months, for each of the forty-eight months in which the trap was working. The results showed that, under the conditions of the locality, in the summer the limiting factor in insect numbers was moisture, and in the winter temperature. Thus, a wet June results in more insects in July, August and September, but a warm June does not increase the number of insects in the following months.

Owing to the war, it was impossible to continue the light trap on which most of this work has been based. It is most important the work should be resumed with several traps, so as to study the climatic effects on single species of insects. Also the work should be repeated elsewhere in England or abroad, to see if the effects obtained here are general or only local in application.

Population studies

These studies during the period under review have been confined to the one dealing with the button-top midge at Syston, Leicestershire (17) which was discontinued owing to the difficulty of travel during war time, one on the carrot fly in north Lincolnshire and east Nottinghamshire (23) which was also discontinued owing to war-time difficulties, an incidental study of an unusual outbreak of vapourer moth caterpillars in Caernarvonshire in 1942 (24, 25) and the continuation of the original Rothamsted population study of the wheat-blossom midges on Broadbalk which was initiated in 1927 (20).

The last-mentioned study has reached a stage at which it is attracting world-wide attention as what promises to be a Rothamsted classical study. Already it is being used in courses on ecology both at Oxford and Cambridge in this country and at universities overseas.

Two gall midges are involved, *Contarinia tritici* which is the lemon-coloured wheat-blossom midge and whose larvae are the same colour and gregarious, and *Sitodiplosis mosellana* which is the

orange-coloured wheat-blossom midge and whose larvae are the same colour and almost solitary. Their larvae in the first species present grain formation and in the second cause shrunken grain.

Since 1927 *C. tritici* has had three or four, more or less well defined peaks of abundance, the first in 1929-31 with about 19,000 larvae per 500 ears, the second in 1935 with about 4,000 larvae, the third about 1941 with about 2,000 larvae, and the fourth in 1945 with nearly 25,000 larvae, per 500 ears. The trough years have been 1927, 1933, 1938 and 1944. *S. mosellana* similarly has occurred in peak numbers in 1931, 1935, 1941 and 1945 with troughs in 1927-29, 1933, 1938 and 1944. The grain infestation of both these midges also indicates that there have been four peaks in the last nineteen years, namely in 1931, 1935, 1941 and 1945.

The inter-relationship of the midges and their host plant has been shown to be so close that a reasonable estimate of the forwardness of the year's crop can be obtained by observing the emergence dates of the wheat-blossom midges in an insectary, and also that the percentage grain attacked gives a useful first estimate of the crop yield (30).

It has also been shown that the larvae of the midges do not invariably emerge as midges the year following their presence on the wheat (26). Thus in the case of *C. tritici* it is known that besides sometimes emerging as midges the same year as the larvae attacked the wheat, the larvae sometimes remain two winters in the soil. Its parasites also can remain dormant for the same period. This delay of emergence is even more pronounced in the case of *S. mosellana*. Specimens of this species emerged in 1945 from larvae that were on the wheat in 1939, and so it is now known that they can spend at least six winters in the soil. The observations are continuing, but it is already clear that 1944 was a trough year for incidence of these midges on the wheat at least partly because 1944 was a bad year for emergence, whereas 1945 when the present peak of abundance was first manifest was a much better year for emergence.

Population studies: mathematical analysis of mixed populations

Arising out of the light-trap studies on the relation of insect numbers to climatic and weather conditions, a statistical study of the data obtained was made and it was found that there was a mathematical order in the relative abundance of different species of insects in a random sample from a mixed population as given, for example, by the light trap. Professor R. A. Fisher co-operated in the work (84) and found that the frequency of species in the sample could be best expressed by a logarithmic series. The results were applied to insects in the light trap (236) and it was found that in a random sample the number of species with 1, 2, 3 or more individuals, closely followed the series ;

$$n_1 : \frac{n_1 x}{2} : \frac{n_1 x^2}{3} : \frac{n_1 x^3}{4}$$

where n_1 is the number of species represented by one individual and x a constant, for the sample, less than unity. The sum of both individuals and of species in the series is finite, so that if in any

random sample the numbers of individuals and of species is known, then n_1 and x can be calculated.

If a larger or smaller sample is taken by the same method from the same population, there will be different values of n_1 and x; the larger the sample, the closer x is to unity. It has been shown, however, both theoretically and practically by the light-trap results, that for all samples of whatever size from the same population taken by the same method, the ratio of $n_1 \div x$ is constant. This ratio has been designated " Index of Diversity " and is a property of the population sampled. If the population is rich in species, it is high : if poor in species, low. This has proved to be a very valuable new ecological weapon for distinguishing populations of different structure and composition.

The application of the general properties of the logarithmic series has been extended to light-trap catches of insects in the United States (93) : the number of species of plants in different areas (87) and 85) : the number of lice on the heads of infested men (87) : the number of British nesting birds : of mosquitos caught in a light trap and of butterflies caught in Malaya (87). It has also been found to apply closely to the number of species in genera of both plants and animals (87) : and even to the number of publications published by entomologists in one year (86).

Work is continuing on this, as it is thought that it may lead to a fundamental understanding of the relative abundance of species in an insect population, and hence of the balance of species numbers and the causes of displacement and outbreaks of insect pests.

Studies on Cecidomyidae

The underlying policy with regard to this work has always been two-fold ; the provision of information to the advisory services and research workers throughout the world, and in the second place, the increase of the knowledge concerning this group of flies. The latter has involved what might be termed neo-systematic or bio-systematic studies.

The demands for information have been very widespread. Thus since 1937 two check lists of Cecidomyidae have been published, one relating to New Zealand (5), the other with Oceania (3).

Requests for identifications involving the describing of new species have included : midges from beech buds in Germany (6), from sesame or simsim in Tanganyika Territory (7), from coffee in Tanganyika Territory and the Belgian Congo (10), from a grass *Stenotaphrum dimidiatum* and from citrus blossom in Mauritius (31), from apple and black-currant blossom from Japan and Finland respectively (13, 18) and from the leaves of *Hydrangea* in Cornwall (28).

Advice has been sought regarding the identity of gall midges reared on a variety of plants including tomato, hibiscus, egg-plant, etc. in the Hawaiian Islands.

The increase in seed production has resulted in inquiries concerning midges found in grass seed (9, 15) and stored seeds (27). In New Zealand, likewise, trouble has been caused to cocksfoot grass-seed production, and this restarted an investigation into the status of the gall midges affecting the seeding of this grass in Great Britain (14). It was this which led to the interesting fact that one

of the well-known meadow-foxtail grass gall midges is now breeding successfully on cocksfoot in England, Ireland and New Zealand. The individuals reared from both these grasses in the first two named countries are apparently identical on morphological evidence whereas those in New Zealand exhibit differences. From this it has been inferred that the change-over in New Zealand took place some years ago but that in Great Britain the change-over is more recent. Considerable help has been given to a survey of the gall midges of cocksfoot grass in Devon that was initiated by Seale-Hayne Agricultural College, half the samples collected being studied at Rothamsted.

The increase of the chrysanthemum midge in England has led to an intensive study being made of this species both from the biological (11, 12) and from the host-plant-range (8) points of view.

Other host-plant-range studies have included the arabis midge and the black-currant leaf midge as well as the hawthorn-stem midge (8).

The recent outbreaks of the raspberry-cane midge in the raspberry trials at Wisley led to an investigation as to whether this midge can oviposit successfully on undamaged canes, the position of healthy and parasitised larvae and the host-plant range (32).

During the war years, when inquiries from abroad fell cinsiderably in numbers, advantage was taken to get the work on *Gall Midges of Economic Importance* throughout the world nearer completion. As a result arrangements have now been completed for its publication in eight volumes. The first two, *Gall Midges of Vegetable and Root Crops* and *Gall Midges of Fodder Crops*, are due for publication in the spring of 1946.

Insect migration

The work described in the previous report has been continued and was considerably helped between 1938 and 1940 by a grant from the Leverhulme Foundation, which enabled extra clerical and scientific assistance to be employed. Progress has been made in the collection of information on a large number of British insects, particularly through the co-operation of the Insect Immigration Committee of the South-Eastern Union of Scientific Societies, who collect records of immigrant insects from amateurs throughout the country, and forward them to Rothamsted for filing and study.

From an examination of these, and from other information, reports have been published on the migrations of the Cabbage White Butterfly (*Pieris brassicae*) (53, 69 and 78), the Silver Y Moth (*Plusia gamma*) (52, 48 and 90), and the Silver Striped Hawk Moth (*Celerio lineata* (5). The two former of these are pests in Britain and the latter a pest of vines in the south of France and only a rarity in this country. A race of the Silver Striped Hawk Moth occurs in North America, and by a comparison of the dates of outbreaks of the two races it has been shown (51) that there is a statistically significant tendency for the outbreaks to occur simultaneously on both sides of the Atlantic. After this had been established, a similar investigation was made in the case of the Painted Lady Butterfly (*Vanessa cardui*), and a similar result was obtained (78).

Records continue to come in from all over the world, and these

have been summarised in a series of papers for India (68), Africa (70), America (67, 64 and 70) and Australia and Asia (73). Observations on migration made and collected during C. B. Williams's visit to South America have also been published separately (91 and in the Press).

In co-operation with Miss M. E. Gibbs and Mr. J. A. Downes, a series of " Studies in the Migration of Lepidoptera " was published in 1942 (78) summarising most of the work of the last ten years and including several new types of investigation, including a statistical study of the years of occurrence of 35 species of British migrating Lepidoptera in Great Britain in the last sixty years. It was found that there was a distinct tendency for the species to be associated in groups. The species within one group tend to occur in numbers in the same years together, but species in other groups tend to be rare in those years.

There was also included in the report a discussion on the sense of orientation of insects during migration : the evolutionary aspect of the question of the return flight : the possibility of marking insects to trace their movements : and a very full account of the occurrence in England of the Monarch Butterfly (*Danaus plexippus*).

Recently a short investigation was made on the food reserve of migrant insects in the form of stored fat (90). A large number of Silver Y Moths was caught in a searchlight, apparently during a migration, and a number of these were dried and weighed individually before and after extracting with ether. The results show the amount of fat stored in the body, and also the variation from one individual to another.

Aleurodidea (white flies)

An investigation was made during the years 1936-38 on the British species of Aleurodidea, some of which, especially the greenhouse white-fly and the cabbage white-fly, are of considerable economic importance. Two papers (62 and 63) give the results of this work.

In the former, two new species found in greenhouses at Kew are described, and the second deals particularly with certain British native species which are closely related to each other and difficult to distinguish. In some cases distinguishing features were found, but in others they were believed to be only one species on several food plants.

A list of seventeen British species is given, of which thirteen were studied. Keys for the identification of these last were given, and observations on parasitism, in the field and experimentally in the laboratory, were also discussed.

Miscellaneous

The life history of the oil or blister beetle, *Meloe proscarabaeus L.*, has been studied (58) following its appearance in sufficient numbers to annoy lady golfers.

A bulletin was prepared for the Imperial Bureau of Pastures and Forage Crops, Aberystwyth, entitled " Insect and other pests injurious to the production of seed in herbage and forage crops " (4).

PUBLICATIONS

1. ANON. 1943. *Slugs.* Mon. Sci. News, June.

2. ANON. 1944. *Do you know your slugs ?* The Countryman, **30**, 58-59. Popular account of slug investigations going on at Rothamsted.

3. BARNES, H. F. 1937. *Check list of Cecidomyidae of Oceania.* Occasional Papers of Bernice P. Bishop Museum, Honolulu, **13**, 61-66.

The gall midges recorded from the area bounded by Hawaii on the north, by the Bonin, Bismark and Trobriand Islands on the west, by New Caledonia and Rapa on the south, and by Easter Island and Galapagos on the east.

4. BARNES, H. F. 1937. *Insects and other pests injurious to the production of seed in herbage and forage crops.* Imp. Bur. Past. For. Crops, Bull., 20.

Summary of the available information in the light of the most recent research. The lack of control measures in so many instances is disturbing.

5. BARNES, H. F. 1937. *Check list of the Cecidomyidae of New Zealand.* Proc. Roy. Soc. New Zealand, **67**, 115-121.

Thirty-four species have so far been recorded, of these five have undoubtedly been introduced, namely *Dasyneura alopecuri* (Reuter) and *Stenodiplosis geniculati* (Reuter), two of the meadow foxtail grass midges ; *Dasyneura pyri* (Bouché), the leaf-curling pear midge ; *Mayetiola destructor* (Say), the Hessian fly ; and *Contarinia tritici* (Kirby), one of the wheat-blossom midges.

6. BARNES, H. F. 1939. *A new gall midge attacking beech buds.* Arb. phys. angew. Ent. Berlin-Dahlem, **6** (1), 41-43.

Description of *Dasyneura fagicola* found in Germany attacking beech buds.

7. BARNES, H. F. 1939. *Two new gall midges from* Sesamum angustifolium. Ann. and Mag. Nat. Hist., **3**, 453-456.

Descriptions of two new gall midges attacking the blossoms of cultivated *Sesamum angustifolium* in Tanganyika Territory.

8. BARNES, H. F. 1939. *Some gall midge species and their host plant range.* Ann. App. Biol., **26**, 318-347.

Emphasis is laid on the need for using biological in addition to morphological characters, in the separation of closely allied species of gall midges. An analysis is given of the recorded host plant range of species of the genus *Asphondylia*, showing that the great majority of species, 103 out of 133, are recorded from only one species of plant.

Four studies concerning gall midges of economic importance are presented in support of the plea for more intensive biological studies. The first deals with three supposed species which make terminal leaf galls on various species of Arabis. As a result of study it is concluded that only one true species causes the damage. The species is *Dasyneura alpestris* (Kieffer) de Meijere, while *D. schneideri* Rübsaamen and *D. arabis* Barnes are synonyms. The midge involved attacks certain species of the subgenus *Euarabis* and one other species which may belong to the subgenus *Lomaspora*.

The second study deals with the chrysanthemum gall midge, *Diarthronomyia* sp. Its distribution on commercial chrysanthemums is traced from its initial record as a pest in the United States of America and Canada in 1915. It appeared in England in 1927 and again in 1936, on both occasions the infestation being traceable to chrysanthemum varieties imported from the U.S.A. More recently it has appeared in Denmark (1934), in Sweden (1935), in Finland (1936) and in Northern Ireland (1937). Experiments on the host plant range are described. Oviposition only took place on nearly all the *Chrysanthemum* spp. subjected to trial. Galls were formed on *C. Parthenium*, but no adults developed. The midge was bred successfully only on commercial varieties of autumn chrysanthemums, *C. indicum* L., *C. rubellum* Sealy, *C. indicum* var. *azaleoides* (*C. azaleanum* Hort.) and *C.* Korean Apollo. In addition, eggs were laid on such plants as *Matricaria inodora, Anthemis nobilis, A. Cotula, Achillea Millefolium* and *Senecio vulgaris* : in these cases no galls were formed. The conclusion is reached that the midge of commercial chrys-

anthemums should be regarded as distinct and separate from *Diarthrinomyia hypogaea* F.Lw. of wild *Chrysanthemum* spp. recorded from Central Europe.

The third study involves three species of the genus Dasyneura whose larvae cause the leaves of *Rubus* spp., *Ribes nigrum* and *R. Grossularia* to become twisted and crinkled. Attempts to induce *Dasyneura tetensi* Rübsaamen of black currant to attack gooseberry always failed. *D. tetensi* would not mate with *D. plicatrix* H.Lw. of blackberry. In spite of two records in the literature of *D. tetensi* attacking gooseberry, the conclusion is reached that the three species are genuine species—*D. tetensi* Rübsaamen confining its attention to black currant, *D. ribicola* Kieffer limiting itself to gooseberry, and *D. plicatrix* H.Lw. only attacking species of Rubus.

The fourth study describes the biology of the newly discovered hawthorn stem midge and compares its bionomics with those of the red bud borer (*Thomasiniana oculiperda* Rübsaamen) and the raspberry cane midge (*T. theobaldi* Barnes). It is concluded that the three midges are distinct species and a description is added of the hawthorn stem midge to which the name *Thomasiniana crataegi* sp. n. is given.

9. Barnes, H. F. 1939. *Grass-seed* Dasyneura *gall midges together with the descriptions of two new species.* Arb. phys. angew. Ent. Berlin-Dahlem, **6** (**2**), 171-175.

Including descriptions of two new gall midges, *Dasyneura festucae* whose larvae prevent seed formation in creeping red fescue in England, and *Dasyneura triseti* whose larvae prevent seed formation in golden oat-grass in the Austrian Alps.

10. Barnes, H. F. 1939. *Gall midges* (*Cecidomyidae*) *associated with coffee.* Rev. Zool. Bot. Afr. **32**, 324-336.

A résumé of what is known concerning gall midges associated with coffee in Tanganyika Territory, the Belgian Congo, Uganda, Madagascar and the Seychelles. The paper includes descriptions of two new species whose larvae live in the flowers, one new species whose larvae feed on coffee rust, and two new species whose larvae are predacious on coccids attacking coffee.

11. Barnes, H. F. 1939. *The chrysanthemum midge.* J. Royal Hort. Soc. **64**, 503-506.

A popular account of the host plant range and life history of the chrysanthemum midge in England.

12. Barnes, H. F. 1940. *The biology of the chrysanthemum midge in England.* Ann. App. Biol., **27**, 71-91.

The life history of the chrysanthemum midge has been worked out at Harpenden, England both under laboratory and unheated glass-house conditions. Important points have been emphasised in §7.

The midge breeds continuously throughout the year, the generations following each other more rapidly as the hottest weather approaches. Under unheated glasshouse conditions five generations occurred between March, 1938 and March, 1939. Considerable overlapping takes place. There was no evidence of hibernation or aestivation. Emergence has been observed when there was frost on the plants, but the threshold temperature for mating and egg-laying appears to be slightly above freezing-point. No ceiling temperature or upper limit for breeding was encountered. Field notes have shown that the midge behaves in commercial nurseries in much the same way as in the experiments conducted in the unheated glasshouse throughout the year.

For total eradication it is shown that fumigation and spraying are not economical. Dipping the cuttings in nicotine-soft soap solution greatly reduces the numbers of developing midges. The most hopeful method of eradicating the pest seems to be cutting down the entire plant, then isolating the cut down stools and, subsequently using the new growth for cuttings.

13. Barnes, H. F. 1940. *Two new pests of apple and black currant,* Bull. Ent. Res. **31**, 85-87.

Includes a description of *Dasyneura ribis*, sp. n. whose larvae attack black-currant flowers in Finland.

14. Barnes, H. F. 1940. *The gall midges attacking the seed-heads of cocksfoot,* Dactylis glomerata, *L.* Bull. Ent. Res., **31**, 111-119.

An account is given of four gall midges whose larvae damage the seed of cocksfoot, viz., *Contarinia dactylidis* (H. Lw.), *Dasyneura dactylidis*, Metcalfe, *Sitodiplosis dactylidis* which is described from England and Ireland in the present paper, and *Stenodiplosis geniculati* (Reuter). The occurrence of predacious midges of the genus *Lestodiplosis* is also noted. A short section is devoted to characters by which these midges can be distinguished.

Stenodiplosis geniculati is recorded from one English and two Irish localities on cocksfoot grass for the first time, hitherto it has always been recorded from foxtail. These midges, together with some experimentally bred on cocksfoot from foxtail parents, exhibit the typical characters of this species.

A new variety, *Stenodiplosis geniculati* var. *dactylidis*, is described from cocksfoot in New Zealand.

In a discussion of the host-plant specificity of gall midges attacking grass seeds, it is suggested that the present discovery of *S. geniculati* on cocksfoot in England and Ireland and the occurrence in New Zealand of this new variety exhibiting distinct morphological characters are two steps in the evolution of a new species.

15. Barnes, H. F. 1940. *Gall midges and grass seed production.* J. Board Greenkeep. Res. **6**, 118.

A popular résumé of gall midges preventing grass seed production.

16. Barnes, H. F. and Weil, J. W. 1940. *Meta slug control : experiments on possible substitutes for bran.* Gardeners' Chron., **108**, 20.

Experiments to discover a wartime substitute for bran for the control of slugs by the metaldehyde-bran method, show that with one exception, all the substances which have been shown to be as good or better than bran, are foodstuffs. The exception is tea leaves. Another fact which is apparent is that the metaldehyde is not the main attractant and the success of the treatment does depend on the choice of substances used with it.

17. Barnes, H. F. 1940. *Studies in fluctuations in insect populations.* VII. *The buttontop midge* (Rhabdophaga heterobia) *at Syston,* 1934-39. J. Anim. Ecol., **9**, 202-214.

This study of the gall midge *Rhabdophaga heterobia* H.Lw. is a continuation of the third study in the series, which covered the years 1928-33, and the data for the years 1934-9 are given. In addition, the results of the whole twelve years 1928-39 are reviewed.

The changes in the total insect population (midge and parasites) have been discussed. Birds are shown to play an important role in reducing the total population during the winter months. The drop in 1930 was probably caused by a drought in the late summer of 1929. The hot summers of 1933 and 1934, acting through the plant growth, caused similar reductions in 1934 and 1935. Since 1936 the population has steadily fallen because the willows have been allowed to go out of cultivation and become exterminated as a result of grazing.

A positive correlation has been found to exist between the numbers of midges and parasites, but there is no correlation between the size of the total population (midges and parasites) and the percentage parasitism. The changes from year to year in the numbers of the total population and in those of the parasites are almost identical. It is concluded that relative parasitism as high as 64 per cent. exerts no control on the number of midges and also that the parasites do not become more efficient at high population levels than at low ones and so cannot have any balancing effect.

The readiness of the midge and its parasites to emerge in response to extra warmth given in March has been demonstrated. Under normal conditions dates of first emergence have varied from 13 April to 16 May in the case of the midge, but the variation is less when the weeks of maximum emergences are considered. The emergence of the parasites usually follows closely that of the midge, but in some years the weather appears to act differentially on the midge and its parasites as regards the dates of emergence.

18. Barnes, H. F. 1939. Contarinia mali *sp. n. the apple blossom midge, with notes on the more common gall midges attacking apple and pear.* Kontyu **7, 13** (June, 1939), Ent. Soc. of Nippon, 126-132.

Includes description of a new gall midge attacking apple blossom in Japan. The larvae prevent the flower buds from opening.

19. Barnes, H. F. 1941. *Sampling for leatherjackets with orthodichlorobenzene emulsion.* Ann. Appl. Biol., **28**, 23-28.

The orthodichlorobenzene method is satisfactory for estimating rapidly the numbers of leatherjackets present early in the year, providing it is used on suitable days, i.e., damp rather than dry ones, warm rather than frosty ones. About 80 per cent. of the leatherjacket population is obtained. It is unreliable later in the season when the leatherjackets are approaching their fully fed stage. For one reason the leatherjackets appear to become immune to orthodichlorobenzene, and, secondly, at this period a definite movement away from the original feeding site appears to take place. The dates when the treatment becomes ineffective vary from year to year. Generally speaking it is effective till the end of March, but it may be used some years throughout April with good results.

20. Barnes, H. F. 1941. *Studies of fluctuations in insect populations.* VIII. *The wheat blossom midges on Broadbalk, 1932-40, with a discussion of the results obtained, 1927-40.* J. Anim. Ecol., **10**, 94-120.

This is the continuation of the investigation started in 1927 of the wheat blossom midges, *Contarinia tritici* Kirby and *Sitodiplosis mosellana* Gehin, as they occur in the field of permanent wheat (Broadbalk) at Rothamsted Experimental Station.

Data are given for the years 1932-40 relating to their biology, viz., emergence, number of larvae per infested grain, larvae overwintering more than one winter and alternative host plants, as well as to the degree of infestation of the wheat and the relative parasitism of the midges.

The results of the whole fourteen years' continuous study are considered. The date of emergence is correlated with the wheat-ear emergence, and it appears that both are correlated with the harvesting dates. Thus knowing the dates of either the midge's emergence or the wheat-ear emergence, one can apparently predict in June the date of harvest.

There seem to be cycles (about five years) of abundance of *C. tritici* and *S. mosellana*, either considered separately or together. Years in which there are high numbers of wheat midge larvae are followed by years of high relative parasitism, and years of low larval number are followed by years of low relative parasitism in both species of midge. High relative parasitism accompanies low winter survival of midges and parasites, low relative parasitism accompanies high winter survival.

The percentage grain attack is negatively correlated with the yield of wheat. If there is no adequate compensation in the wheat ear that has been attacked between the time of the attack and harvest, then the midges must be considered as pests. If on the other hand there is compensation, the numbers of midge larvae can only be regarded as an indication of the size of the yield, or in other words a measure of those climatic conditions during the previous months which influence the yield of wheat.

Manuring does not affect the intensity of midge attack.

The effect of one year's fallowing is to reduce the infestation by the midges, although this is somewhat masked on Broadbalk field by positional differences in infestation. One part of the field is always comparatively more heavily infested than the rest. This effect of fallowing seems to have disappeared by the third successive crop, i.e., non-rotation increases the infestation by both midges.

The effect of one year's fallowing on the number of grains of wheat is a marked increase in the first crop after the fallow. The number of grains in the second crop after fallow, while considerably less, is appreciably greater than that of the third and fourth crops.

In the years when the number of blind spikelets of wheat is high, the number of possible grains and the actual number of grains formed are low. Thus by estimating the number of blind spikelets between 5 and 16 July one can obtain ar early estimate of the number of grains per ear at harvest. But unfortunately the number of grains formed per ear does not necessarily indicate the yield, since the yield would be measured by the number of ears or grains per acre and the weight per grain.

21. Barnes, H. F., and Weil, J. W. 1941. *Slug control with metaldehyde.* Gardeners' Chron., **110**, 144.

Foodstuffs attract the slugs to the baits. Metaldehyde alone, metaldehyde

with non-foodstuffs, and bran without metaldehyde are not such efficient baits as foodstuffs with metaldehyde.

Foodstuffs with metaldehyde form the most efficient slug killers, the more nutritive foodstuffs being more efficient than bran.

22. Barnes, H. F. and Weil, J. W. 1942. *Baiting slugs using metaldehyde mixed with various substances.* Ann. Appl. Biol., **29**, 56-68.

The literature concerning mixtures of other substances with metaldehyde for use as slug baits has been briefly reviewed. An account has been given of the comparison of the numbers caught by forty-four substances and by bran in metaldehyde baits. It is shown that baits containing feeding stuffs are undoubtedly better than baits of metaldehyde alone or metaldehyde mixed with non-feeding stuffs, such as soil, sand, etc. Nutritive feeding stuffs, such as cakes and meals, are better as a group than roughage feeding stuffs, such as bran. The efficiency of metaldehyde baits is discussed. The range of effectiveness of the baits, the proportion of slugs visiting the baits dying, the speed of annihilation of a slug population, the most economical strength of metaldehyde to use, as well as the mixing of the baits and their distribution, are points which need further investigation. Meanwhile, it is suggested that it is worth while using small quantities of a feeding stuff in order to save much larger quantities of crops which are themselves feeding stuffs. A large slug population can be greatly reduced by a single application of metaldehyde plus a feeding stuff and can be subsequently prevented, by the use of metaldehyde and an inert or non-feeding stuff diluent, from reaching undue proportions again.

23. Barnes, H. F. 1942. *Studies of fluctuations in insect populations : IX. the carrot-fly* (Psila rosae) *in 1936-41.* J. Anim. Ecol., **2**, 69-81.

This is the ninth paper dealing with fluctuations in insect populations collected in the field and studied in an out-door unheated insectary. The previous eight papers have dealt with various species of gall midges.

A satisfactory method of assessing the yearly abundance of the carrot-fly and its parasites is described. Data are given for the years 1936-41.

The dates of emergence of the adult flies for the same period are also given.

The preparation of standard tables for the dates of hatching, emergence, etc., of insect pests is discussed briefly. For this purpose the setting up of an insect phenological station is suggested. The function of such a station would be to provide local growers, through their advisers, with information as to the earliness or lateness of the season.

24. Barnes, H. F. 1942. *Unusual abundance of* Notolophus (Orgyia) antiqua *L.* (*Lep., Lymantriidae*). Ent. Mon. Mag., **78**, 240.

An estimate showed that there was a quarter of a million larvae of the Vapourer moth on the eastern half of the perimeter of a circular patch roughly fifty yards in diameter of Bilberry on the mountains behind Penmaenmawr, North Wales.

25. Barnes, H. F. 1942. *A further note on the unusual abundance of Orgyia antiqua L.* (*Lep. Lymantriidae*). Ent. Mon. Mag., **79**, 47.

A Braconid parasite *Rhogas geniculator* Nees and two species of parasitic Tachinid flies were emerged from the larvae of the Vapourer moth. The final figures of the emergence were 95 per cent. Vapourer moth, 4 per cent. Tachinidae, and 1 per cent. Braconidae.

26. Barnes, H. F. 1943. *Studies of fluctuations in insect populations.* X. *Prolonged larval life and delayed subsequent emergence of the adult gall midge.* J. Anim. Ecol., **12**, 137-8.

The emergence of *Contarinia tritici* adults can occur in the autumn of the same year as the larvae attack the wheat, during the next spring and after a lapse of two winters. Its parasites generally emerge after the first winter but have been known not to emerge until after the second.

The emergence of *Sitodiplosis mosellana* takes place up to four years after the larvae have attacked the wheat, but not later in the same year. Its parasites can survive two winters in the soil.

The effect of this variability in the duration of the larval stage in preserving the race and as a cause of sudden increases in numbers is pointed out.

27. Barnes, H. F. 1944. *Gall midge larvae among stored seeds.* J. Roy. Hort. Soc., **69**, 242-243.

A note pointing out that gall midge larvae found among stored seeds are usually non-injurious. The injurious gall midges leave the seed heads of plants, usually before the seed is harvested. Those found in stored seeds are inquilines or else are predacious feeding on mites.

28. Barnes, H. F. 1944. Clinodiplosis hydrangeae *sp. n.* (*Cecidomyidae*) *causing a leaf blister gall on* Hydrangea hortensis. Entom., **77**, 129-130.

Description of a new gall midge *Clinodiplosis hydrangeae* whose larvae cause blister galls on the leaves of *Hydrangea hortensis* in Cornwall.

29. Barnes, H. F. 1944. *Discussion on slugs.* I. *Introduction. Seasonal activity of slugs.* Ann. Appl. Biol., **31**, 160-163.

A description of a sampling method involving the collection of slugs at night with an electric torch by means of which the seasonal activity of slugs can be accurately determined.

30. Barnes, H. F. and Weil, J. W. 1944. *Studies of fluctuations in insect populations.* XI. *The interrelationship of the wheat blossom midges and their host plant.* Ann. Appl. Biol., **31**, 231-234.

The date of wheat blossom midge emergence in an insectary some distance away from the growing wheat can give as reliable an estimate of the forwardness of the crop as field observation of the date of ear emergence. The percentage grain attacked by the wheat blossom midges, which can be assessed by routine workers without any special experience of wheat, can give in early July a useful first estimate of the crop yield.

31. Barnes, H. F. 1944. *Two new gall midges from Mauritius.* Bull. Ent. Res., **35**, 211-213.

Descriptions of two new gall midges, *Stenodiplosis stenotaphri* and *Contarinia citri*, whose larvae respectively prevent seed formation in the grass *Stenotaphrum dimidiatum*, and the normal opening of *Citrus* blossoms in Mauritius.

32. Barnes, H. F. 1944. *Investigations on the raspberry cane midge 1943-44.* Journ. Roy. Hort. Soc., **69**, 370-375.

The raspberry cane midge prefers to lay its eggs on undamaged raspberry canes. Those larvae which are found on raspberry canes during the winter are parasitised, whereas the healthy larvae spend the winter on the soil. Experiments on the host plant range of this midge showed that it would breed successfully on raspberry, giant himalayan blackberry and loganberry. On one occasion, two individuals were bred successfully on wild rose. On the other hand, oviposition took place on wild and American cut leaf blackberry, cultivated rose, apple, hawthorn, plum and quince, but on these plants no G_1 adults were reared. Oviposition did not take place on cherry, black and red currant, gooseberry or worcesterberry. It is considered wisest for the present to regard the raspberry cane midge as distinct from the hawthorn stem midge and the red bud borer, because outbreaks of these three midges do not occur simultaneously. For example, the latest outbreak of the raspberry cane midge was at Wisley in 1943, on raspberries, but neither the hawthorn nor the roses in the area suffered any attack from this group of midges.

33. Barnes, H. F. and Weil, J. W. 1944. *Slugs in gardens: their numbers, activities and distribution, Part I.* J. Anim. Ecol., **13**, 140-175.

The paper gives the results of an ecological study, extending over three years in certain gardens at Harpenden, Herts, of about 100,000 slugs. It is pointed out that the straw-coloured young of *Arion ater* are quite different in appearance from the more mature individuals and may easily be thought to be a distinct species. An attempt has been made to clear up the confusion that has existed regarding the separation of the three species of *Milax*, viz., *gagates*, *gracilis* and *sowerbyi*.

The present investigations concern nine species—*Arion ater*, *A. circumscriptus*, *A. hortensis*, *A. subfuscus*, *Milax gracilis*, *M. sowerbyi*, *Agriolimax reticulatus*, *Limax maximus* and *L. flavus*. Notes are given on the characters used by the authors in distinguishing these species. A key is appended for the

separation of fifteen out of the twenty or more species which have been recorded in the British Isles.

The areas used have been about fifty gardens chiefly in the Moreton End district of Harpenden. While one garden has been the main scene of the investigations, six others have been visited throughout the year and others at less frequent intervals.

The method employed has been the collection of slugs seen with the aid of an electric torch chiefly on what have been thought to be favourable nights for slug activity, warm, moist, still nights being considered the ideal. The unit sample has been the slugs able to be picked up without searching during a thirty minute walk round the area under immediate consideration. The method and its applications are fully described.

Some idea of the abundance of the slugs that are active after dark in quite ordinary suburban gardens may be gathered from the fact that 30,626 have been collected in 170 half-hour periods during 1942 and 38,416 in 181 half-hours in 1943 without the use of any baits, just by walking round the gardens with an electric torch. This gives an average for the two years of nearly 200 per half-hour. It should be remembered that the fifty or so gardens have not been chosen because they have been suspected of harbouring an unusual number of these animals. When considering the average number per half-hour one must also recall that the collecting has been done on what were judged to be favourable nights for activity and throughout the year. In the garden, roughly one-fifth of an acre in area, that has been sampled most frequently (100 times) the average per half-hour is nearly 276 ; in another garden, one about half this size, that has been sampled twenty-three times at all times of the year, the average is 296. The largest number ever picked up in any garden during half an hour has been 570 and another half-hour's collection made in the same garden over the same route after an interval of only half an hour yielded an additional 517.

Three species—*Arion hortensis*, *Agriolimax reticulatus* and *Milax gracilis*—have been virtually in every garden, although some of them have been visited only once. The average numbers of these picked up per half-hour during the two years are respectively about 60, 50 and 40, the 1942 and 1943 totals being roughly 10,000, 11,000 ; 9,000, 9,000 ; and 5,000, 9,000. The largest numbers of these three species collected in a single half-hour are 315, 165 and 371.

Three other species—*Arion subfuscus*, *Milax sowerbyi* and *Arion ater*—have occurred sufficiently abundantly to enable 100 or more of them to be picked up in a single half-hour. The yearly totals of these species have been roughly 3,000, 4,000 ; 1,000, 2,000 ; and 1,000, 1,000. The remaining three species—*Arion circumscriptus*, *Limax maximus* and *L. flavus*—have been much less common, the totals for the two years being only 245, 222 and 10.

The section ends with a short discussion on the use of the word " abundance " and the possibility of assessing changes in population by this collecting method of sampling active slugs.

The total number of slugs active after dark on nights suitable for activity has not varied greatly throughout the year and large numbers have been found at all times of the year whenever the weather conditions have been favourable. But it is shown that each species has its own well-defined rhythm in numbers to be found active. These pulsations occur annually and in every garden with remarkable regularity whether there be large or small numbers of the species present. There have been slight variations in date according to the " earliness " or " lateness " of the year and the " aspect " of the particular garden.

The species do not reach their peak numbers at the same time of the year. Most *Arion ater* have been found active in January ; most *A. subfuscus* in June; *Agriolimax reticulatus* has reached its maximum numbers in June (during 1943 an " early " year) and August-September which is probably more normal ; *Milax sowerbyi* between August and October ; *M. gracilis* in October chiefly, but equally large numbers have been collected even as late in the year as December ; and *Arion hortensis* between October and December, closely associated with *gracilis* but, on the whole, inclined to reach its peak numbers later in the year.

In the discussion various points are briefly mentioned, including the night-to-night fluctuations in numbers of the various species, the fact that the peaks of numbers active coincide with the peaks of the largest sized individuals, except in the case of *Arion ater*, and the relation between the numbers found active and the basic populations.

34. Barnes, H. F. and Weil, J. W. 1945. *Slugs in gardens; their numbers, activities and distribution, Part II.* J. Anim. Ecol., **14**, 71-105, three coloured plates.

Observations of slugs feeding in gardens indicate that very little of their food consists of plant material grown for human consumption or pleasure. In places where one crop only is grown, e.g., potato patches in the autumn, the damage would be higher owing to the absence of alternative food.

Mating of *Agriolimax reticulatus* and *Arion subfuscus* takes place out in the open on the surface of the ground after dark, the peaks being soon after the peaks of seasonal activity ; the former species also mates to some extent throughout the year, whereas in the latter species mating is restricted to July-October. *A. hortensis* and *ater* usually require some shelter, e.g., dead leaves, under which to mate, while it is presumed the *Milax* species usually mate underground or under cover.

By weighing the slugs, species by species en masse as collected and then calculating the weight per 100 individuals, regular changes in weight throughout the year have been found. This method has been found to be as satisfactory for assessing seasonal changes in weight as the half-hour method of collecting slugs is for measuring seasonal changes in activity numbers. The slugs are heaviest soon after the greatest numbers are found active and at the time when the peak of mating occurs.

The distribution of the species varies from garden to garden. *A. hortensis* and *M. gracilis* are most abundant in the gardens at the bottom of an old river bed slope and decrease steadily until their lowest numbers occur halfway up it. *M. sowerbyi* has a ridge of abundance across the slope. *A. subfuscus* is almost completely absent on the east side of the valley. Two particular gardens form foci of abundance of *L. maximus* and *A. ater* is more abundant in gardens of recent origin in close proximity to coarse grass areas than in old well-established gardens. These distributions have persisted month by month throughout two years.

There is some evidence that each species has its own regular curve of nightly activity, providing of course weather conditions are suitable. In the summer, activity appears to be more closely adjusted to the time of sunset than in the winter. Immature specimens of *A. hortensis* preponderated in steadily decreasing numbers in twilight collections made from May to December.

All species are fully active at about 40°F., but some activity continues until almost freezing point ; below this there is no activity. Some species, e.g., *Milax gracilis*, resume activity after cold spells later than others, e.g., *Agriolimax reticulatus*, perhaps owing to their deeper penetration of the soil.

Lack of surface moisture seems to be one of the factors limiting activity. Slug activity in rainless periods is reduced more at some periods of the year than at others. Rainless periods in the spring have less effect on limiting activity than summer droughts. This is probably due to the different water contents of the soil at these seasons. Activity is reduced while heavy rain is actually falling and also in heavy wind.

The optimum conditions for slug activity may be summarised thus : a warm still night with plenty of surface moisture either in the shape of recent rain or dew.

35. Baweja, K. D. 1937. *The calculation of soil population figures.* J. Anim. Ecol., **6**, 366-367.

By using a sample 3 in. by 4 in. surface dimensions, the population in millions per acre can be calculated from the formula :

$$\frac{x}{2} + \frac{(x-20)}{40}$$

where x = number of organisms per sample.

36. Baweja, K. D. 1939. *Studies of the soil fauna, with special reference to the recolonisation of sterilised soil.* J. Anim. Ecol., **8**, 120-161.

The prominent components of the soil fauna were (of insects) Collembola, Diptera, Coleoptera, Hemiptera and to some extent Hymenoptera and (of other invertebrates) Myriopoda, Arachnida and Oligochaeta. The mean population during an experiment in the control plots varied from 61·2 to 67·6 million and in the sterilised plots from 98·3 to 111·8 million per acre. An analysis of the individual orders and immature forms is included.

The relative proportion of the insects to other invertebrates was considerably affected in the area, viz., from 2 : 1 in the controls to 20 : 1 in one of the sterilised plots. Some of the predominating forms like Onychiuridae, *Anommatus* 12-*striatus*, *Harpalus* sp., etc., failed to maintain their dominance in the sterilised plots, while some rare ones such as Hypogastruridae, Aphididae, *Amischa analis*, *Agriotes* sp., etc., increased enormously, a striking instance being that of Aphididae which increased 43·6 times over the control.

Distinct fluctuations were another feature of the populations. The peak period in the density of their population occurred in late autumn or early winter in the controls and the first set of the sterilised plots. This was caused by the sudden increase of Collembola which was soon followed by an equally sharp decline.

The economic aspects of sterilisation inside glasshouses and of the baked soils in the tropics are discussed from an entomological point of view. Since both are subjected to heavy infestation of soil organisms, the desirability of further investigation is suggested.

A study of the subsoil population showed that a few organisms existed down to a depth of 33 in. Their percentage density varied between 80 and 91 in the top 9 in., being higher in spring than in winter. The reverse phenomenon occurred in deeper layers.

37. Deal, J. 1941. *The temperature preferendum of certain insects.* J. Anim. Ecol., **10**, 323-356.

A description is given of three different types of apparatus experimented with before selecting a linear brass gradient which gave a range of temperature from 10°C. to 35°C. in a straight line gradient. This allowed the insects a choice of about 1°C. in every 4 cm. The relative humidity in such an apparatus varied inversely with the temperature except where food was used, when it remained practically uniform.

The temperature preferendum was tested of twenty-three species of insects from six orders. Insects were chosen to represent different environments or habitats, such as the following : stored product insects, leaf-feeding insects, plant-sucking insects, human parasites, insect parasites and soil insects.

At the cold end of the gradient the metabolic activities of the insects were slowed down to such an extent that many of the species were trapped there, thus giving an apparent preference for the colder end. As a result when insects went to a warmer zone it was considered more significant than when they went to a cold zone.

Insects that were given food in the gradient had a narrower preference zone than when not given food.

In general the preferences of the immature forms tended to coincide with those of the adults of the same species.

With saw-flies (*Pteronides melanaspis*) the males tended to have a wider temperature range than did the females.

The Braconid parasites (*Apanteles congestus*) went to a lower temperature on each successive day they were in the gradient and at the end of three days were alive and quite active. At the same time a surplus stock kept at room temperature were all dead at the end of 1½ days.

38. Evans, A. C. 1938. *Studies in the distribution of nitrogen in insects*, I. Proc. Roy. Ent. Soc. A., **13**, 25-29.

The distribution of nitrogen in the castes of the wasp at various stages of development is discussed. In the adult most of the nitrogen is present in the skeletal and soluble protein fractions, in prepupae little is found in the skeleton, but over 60 per cent. is in the form of soluble protein. Just-emerged wasps probably contain a reserve protein, insoluble in water, which is utilised to complete the hardening of the skeleton.

39. Evans, A. C. 1938. *The effect of the chemical composition of the plant on reproduction and production of winged forms in* Brevicoryne brassicae *L.* (*Aphididae*). Ann. Appl. Biol., **25**, 558-572.

It is shown that under late summer conditions of light the rate of reproduction of the aphis, *Brevicoryne brassicae*, is positively correlated with the nitrogen content of the host plant and, in particular, with the protein content. The formation of winged forms is negatively correlated with the same factors.

The chemical composition of the plant affects the rate of growth, length of larval period and final pupal weights of *Pieris brassicae*. It also influences the amount of food eaten.

40. Evans, A. C. 1938. *A note on the estimation and some properties of insect cuticle.* Proc. Roy. Ent. Soc. A., **13**, 107-110.

It is shown that the cuticle of the mealworm *Tenebrio molitor L.* contains about 60 per cent. protein, which is easily soluble in water, dilute acids and alkalis. The hypothesis is put forward that, in this insect, the material absorbed from the cuticle at the last moult may eventually be utilised to form the major part of the adult cuticle.

41. Evans, A. C. 1939. *The utilisation of food by the larvae of the Buff-tip,* Phalera bucephala (*Linn.*) (*Lepidopt.*) Proc. Roy. Ent. Soc. A., **14**, 25-30.

An accurate method is described for determining in a caterpillar the amount of excreta derived from a given amount of food. Analysis of food and excreta show that about 60 per cent. of the protein, 80 per cent. of the soluble sugars, 60 per cent. of the fat and 35 per cent. of the ash are utilised. Polysaccharides are not utilised. Nitrogen is excreted as ammonia and uric acid.

42. Evans, A. C. 1939. *The utilisation of food by certain Lepidopterous larvae.* Trans. Roy. Ent. Soc. A., **89**, 13-22.

The food relationships of the larvae of *Phalera bucephala, Aglais urticae, Smerinthus populi, Malacosoma neustria* and *Pieris brassicae* have been studied

The co-efficient of utilisation of food falls steadily during the first and second instars of *P. bucephala;* during the third, fourth and fifth instars it fluctuates irregularly. The consumption, utilisation and metabolism of food per gramme of larva per day follows a similar course. The co-efficient of growth increases until the middle of the third instar and then fluctuates irregularly. About 90 per cent. of the water contained in the food is extracted during the first four days of larval life.

The larvae of the species studied utilise and consume food at very different rates. The amounts of carbohydrate, fat and ash utilised per gramme of larva, per day differ very much in the four species.

The nutritive ratio of the larvae is very much lower than that of certain growing mammals, i.e., cattle, sheep and pigs, and the difference seems to be correlated with the chemical composition of the tissues.

43. Evans, A. C. and Goodliffe, E. R. 1939. *The utilisation of food by the larva of the mealworm* Tenebrio molitor *L.* (*Coleopt.*) Proc. Roy. Ent. Soc. A., **14**, 57-62.

The larva of *T. molitor* utilises nearly half of the food which it consumes. Gliadin, glutenin and K_2SO_4 soluble proteins are utilised. About 60 per cent. of the total protein consumed is utilised and about one half of this retained. Mono, di- and poly-saccharides are utilised to different extents. Fatty acids are utilised to a greater extent than unsaponifiable matter. Only a small proportion of the ash is used. About 93 per cent. of the substances utilised have been accounted for.

The larva does not utilise as much of the bran as do ruminants. The nutritive ratio of bran for *T. molitor* is similar to that for ruminants, but is very different from that determined for various lepidopterous caterpillars fed on leaves.

The water content of the larva is maintained above that of its food since the larva retains metabolic water produced from the oxidation of carbohydrates utilised from the food.

44. Evans, A. C. 1941. *A preliminary study of the effects of aphides on the chemical composition of cabbage and field beans.* Ann. Appl. Biol., **28**, 368-371.

Infestation of cabbage by the aphis *Brevicoryne brassicae*, caused a marked decrease in the amount of carbohydrate synthesised but smaller decreases in fat, crude protein and other constituents. Infestation of field beans by the aphis *Aphis fabae* did not have any great effect on the chemical composition of the crop.

45. Evans, A. C. and Gough, H. C. 1942. *Observations on some factors influencing growth in wireworms of the genus* Agriotes *Esch.* Ann. Appl. Biol., **29**, 168-175.

A technique has been worked out for rearing wireworms which permits detailed studies of individuals in relation to food, soil moisture, and other factors. As the wireworm increases in size the moulting process becomes more elaborate. A large portion of the life of the wireworm is spent in non-feeding phases. Newly hatched and half-grown wireworms do not utilise decaying organic matter in the soil. The type of vegetable food on which the wireworm feeds influences its rate of growth.

46. Evans, A. C. 1943. *Value of the pF scale of soil moisture for expressing the soil moisture relations of wireworms.* Nature, **152**, 21-22.

The pF scale of soil moisture suitably expresses the dryness or wetness of a soil in relation to wireworms.

47. Evans, A. C. 1944. *Observations on the biology and physiology of wireworms of the genus* Agriotes *Esch.* Ann. Appl. Biol., **31**, 235-250.

Detailed studies of the growth of wireworms kept at a constant temperature of 15°C. for three years and at natural soil temperatures for two years are presented. It is shown that small wireworms grow rapidly and moult frequently, but large wireworms grow slowly or remain constant in weight and moult infrequently. A basic pattern to account for the decreasing frequency of moulting during the life cycle is presented.

The feeding activity and moulting frequency of a population of wireworms has been studied in detail throughout the season. Definite peaks in feeding activity and moulting frequency occur during the season. A suitable method for the analysis of such activity in a population has been found by dividing the population into groups on a basis of the number of annual moults.

It is shown that increase in dry weight is a more valid estimate of growth than increase in fresh weight.

The cuticle of wireworms is permeable to water, and it is shown that in its relations to soil moisture the wireworm may be regarded as an osmotic system. The pF scale of moisture is shown to be of value in expressing the soil-moisture relations of wireworms. Wireworms feed more actively in moist soil than in dry or wet soil.

48. Fisher, Katherine (Mrs. K. Grant). 1938. *Migrations of the silver Y moth* (Plusia Gamma) *in Great Britain.* J. Anim. Ecol., **7**, 230-247.

Records of the presence and movements in Great Britain of the Moth *Plusia gamma* L. from 1932 to 1937 have been collected from amateur lepidopterists and others by the Insect Immigration Committee of the South Eastern Union of Scientific Societies. The moths have been seen in varying numbers in each of these years, and an account of their distribution in each year is given. Only two winter records have been received, although such records were specially asked for. Both these concerned pupae.

About fifty records give the direction of flight of the moths. From these it is shown that there is a general tendency for northward movements to preponderate in spring, and southward movements in autumn. Westward immigration from across the North Sea seems to occur regularly in mid-August.

A study of records in which direction and strength of wind are given show that wind direction has little or no effect on the direction of migratory flights, and that migrations can take place in adverse winds of Force 4 (13-18 m.p.h.) or in cross winds of Force 5 (19-24 m.p.h.).

Possible starting points of migration have been chosen by prolonging the line of flight backwards from the point of observation to the nearest point on the Continent, and weather conditions for the period immediately preceding the flights have been studied. There appears to be a tendency for migrations to begin in periods of rising barometer, rising or steady temperature, and light or moderate winds. Wind direction at presumed starting points seems to have no influence on the direction of migration.

49. Gough, H. C. 1942. *Laboratory and field experiments on the control of wireworms.* Ann. Appl. Biol., **29**, 280-289.

In a large-scale field experiment, neither naphthalene at 15 cwt. per acre nor calcium sulphide at 350 lb. per acre applied broadcast in February and ploughed in, caused any decrease in the wireworm population. A technique for testing soil insecticides in the laboratory is described and brief notes given on results. In preliminary glasshouse experiments both naphthalene and superphosphate applied near the seed effectively reduced wireworm attack on wheat. A more elaborate experiment on barley did not give such good results.

50. Gough, H. C. and Evans, A. C. 1942. *Some notes on the biology of the click beetles* Agriotes obscurus *L. and* A. sputator *L.* Ann. Appl. Biol., **29**, 275-279.

In a laboratory experiment *Agriotes obscurus* L. females laid significantly more eggs in grass, and significantly fewer eggs in a bare fallow, than in clover, wheat and kale which did not differ significantly from one another. Marked adults of *Agriotes sputator* L. were caught up to 30 yards away from their liberation point, the maximum distance that traps were placed. The ratio of *A. obscurus* to *A. sputator* adults was shown to vary from 1 to 62 to nearly 3 to 1 in nearby fields.

51. Grant, K. J. 1937. *An historical study of the migrations of* Celerio lineata lineata *Fab. and* Celerio lineata livornica *Esp.* (*Lepidoptera*). Trans. Roy. Ent. Soc., **86**, 345-357.

The distribution and outbreaks of the sub-species *Celerio lineata lineata* Fab. in America, and *Celerio lineata livornica* Esp. in the Old World as far as they are known are described. It is suggested that both sub-species originate in semi-desert areas, and this idea is supported in the case of the American sub-species by showing that a correlation exists between outbreaks of moths and a certain sequence of desert rainfall. No correlation is found between European outbreaks and the rainfall of those North African meteorological stations for which records are available, but this may be due to the paucity of suitable figures. A full account is given of the occurrence of *C.l. livornica* in Great Britain, and the main European outbreaks are listed. A correlation is given to show that both years of unusual abundance and absence tend to occur simultaneously in Europe and America, and that the cause of the outbreaks must therefore be sought in some factor common to the two continents. There seems to be some correlation between outbreaks and the sunspot cycle, but the figures are barely significant. The outbreaks tend to occur away from the sunspot minima.

52. Grant, K. J. 1937. *Some recent migrations of the silver Y moth.* J. S.E. Un. Sci. Soc., 1-8.

This is a short account of the immigration into England of *Plusia gamma*, the silver Y moth in the years 1932-36. In 1932-35 there were only small immigrations, but 1936 was one of the largest that has ever been properly recorded and details are given of the dates of arrival of the swarms and the areas in Great Britain covered by the outbreaks.

53. Grant, K. J. 1938. *A migration of cabbage white butterflies in Hertfordshire in May,* 1937. Entomologist, **31**, 103-107.

An account of the migration of cabbage white butterflies which passed through the Harpenden district in May, 1937. It was first noticed on the 17th May, was well marked on the 24th to the 29th May, but diminished rapidly on the 30th and came to an end on the 31st. The flight was almost entirely to the north. Later in the summer, on the 29th July, there was another flight of the same species, this time chiefly to the south-west and west.

54. Ladell, W. R. S. 1938. *Field experiments on the control of wireworms.* Ann. Appl. Biol., **25**, 341-389.

This paper describes an attempt to find out whether it is possible to test chemical measures against wireworms by a field technique similar to that used in fertiliser and varietal experimentation. A full account is given of

three field experiments using old grassland on a heavy " clay-with-flints " soil.

Wireworm populations were ascertained in every case by sampling the soil before and after treatment. The Ladell flotation machine was found rather too small and a modification of the technique using oil drums was adopted. Later, a larger and improved form of the machine was used.

In the first experiment six samples (9 by 9 by 5 inches) were taken in each plot, making a total of 150 soil samples on each occasion. In the second, four samples (9 by 9 by 5 inches) per plot were taken, making a total of 120 before treatment, but after treatment the size of the samples was reduced to 6 by 6 by 5 inches, the number of samples remaining as before. In the third experiment two samples (6 by 6 by 6 inches) per plot were taken, totalling 96 on each occasion.

Local control was introduced in the first two experiments. In addition preliminary experiments were carried out using potatoes and cabbage leaf as baits as a means of estimating wireworm populations. No relationship was found between the number of wireworms obtained in the baits and the actual number in the soil.

The mean density of the original wireworm population was 65, 335 and 277 per square yard respectively in the three experiments. The uneven distribution of the wireworms in the soil resulted in high sampling errors accounting for most of the experimental error. This aspect of the work is discussed fully by W. G. Cochran in the Appendix. No relation was found between the pH of the soil and the density of the wireworm population.

The untreated controls showed changes of -23, +1 and -9 per cent. between the first and second sampling respectively. The biggest drop was obtained when the second sampling was done in July and the smallest difference when the second sampling was done in May. It is suggested that the big drop in July might be due to a downward movement of the wireworms to escape the heat, but the evidence is insufficient to prove this point.

Fumigants " K " and " S " (mixtures of o- and p-dichlorbenzene) reduced the population by 69 and 62 per cent. but had an adverse effect on the crop (sugar beet) in both cases, due to insufficient interval between its application and the drilling of the seed. There was also a residual effect the following year, a reduction in the number of the wireworms and an increase in the plant stand (barley) although there was no significant increase in the final crop yield.

Chlorpicrin reduced the population by 46 and 33 per cent. but there was no harmful effect on the crops (sugar beet and barley). No residual effect was detected.

Fumigant " M " (sodium cyanide) reduced the population by 45 per cent. and increased the yield of the crop (sugar beet). The residual effect was negligible.

Crude naphthalene (" creosote salts ") reduced the population by 60 per cent. tar plus lime by 29 per cent. and ammonium carbonate by 20 per cent. on a summer fallow. Other treatments which all proved ineffective were chlordinitrobenzene, lime alone and superphosphate.

55. Lysaght, A. M. 1937. *An ecological study of a thrips* (Aptinothrips rufus) *and its nematode parasite* (Anguillulina aptini). J. Anim. Ecol., **6**, 169-192.

Aptinothrips rufus Gmelin is abundant on the grass plots of the classical field park grass at Rothamsted Experimental Station. Sampling has been carried out for two years on a number of plots and population counts have been made.

A. rufus is parasitised by *Anguillulina aptini* (Sharga). Some experimental work on the biology of the nematode has been carried out.

The nematode is rarely found on two of the plots and this difference in distribution was found to be constant during 1933 and 1934. There is a very rank growth of *Holcus lanatus* on these two plots and the coarseness of this growth appears to exert an unfavourable effect on the nematodes. Infected insects have been bred on a less sturdy growth of *H. lanatus* under greenhouse conditions.

An account is given of other factors which might affect the distribution of the nematode.

56. Lovibond, B. 1937. *Investigations on the control of leatherjackets : (2) Notes on craneflies and their larvae.* J. Board of Greenkeeping Research, **5**, 12-17.

Notes on the economic species, length of life of adults, egg-laying and early grub stages, as well as the frequency of number of eggs found in *T. paludosa* females caught in the light trap at Rothamsted in 1934.

57. Lovibond, B. 1937. *Investigations on the control of leatherjackets : (3) Some results of breeding and sampling experiments during the current season.* J. Board of Greenkeeping Research, **5**, 107-112.

Notes on the technique of rearing craneflies from the larval stage. Flies were reared from 47 out of 69 localities sampled. Photographs are given of the eggs of three *Tipula* species.

58. Lovibond, B. 1939. Meloe proscarabaeus *L.* J. Board of Greenkeeping Research, **6**, 42-45.

A popular account of what is known concerning the oil or blister beetle (*Meloe proscarabaeus* L.). Photographs are given showing adult bees infested with triangulin larvae, as well as photo-micrographs of the triangulin larvae.

59. Robertson, A. G. 1939. *The nocturnal activity of craneflies (Tipulinae) as indicated by captures in a light trap at Rothamsted.* J. Anim. Ecol., **8**, 300-322.

Seventeen species of craneflies of the sub-family Tipulinae were captured in a light trap in the four years 1933-36. *Tipula paludosa* accounted for about 57 per cent. of the total of nearly 3,400 individuals. Males predominated in *T. paludosa* and three other species, females predominated in *T. oleracea* and three other species. *T. paludosa* is most abundant in September, *Pales flavescens* in June. *T. oleracea* is definitely double-brooded. They are most active just after sunset, and activity is favoured by high minimum temperature and a low daily range. At the time of greatest activity of the group, a rise of about 4° F. in the minimum temperature will effect a doubling of the catch. The same result is produced by a reduction in the daily range of temperature by about 6° F. Cloud and moonlight have a distinct effect, and the optimum conditions are absence of moon and complete cloud. The converse conditions of full moon and no cloud are least favourable, and the catch is eight or nine times as large in the former as in the latter conditions.

60. Thomas, D. C. 1938. *Report on the Hemiptera-Heteroptera taken in the light trap at Rothamsted Experimental Station during the four years* 1933-36. Proc. Roy. Ent. Soc., A, **13**, 19-24.

Nearly 1,500 Hemiptera-Heteroptera were captured in the light trap and identified to species. This gives a short account of these species, their distribution throughout the night, and the sex ratios in the different species. There is also a discussion of the feeding habits of the different species according to whether they are arboreal, ground living or aquatic.

61. Thomas, D. C. 1938. *An annotated list of species of Hemiptera-heteroptera not hitherto recorded for Middlesex.* Entomologist, **31**, 148-153.

The contents of this paper are well covered by the title. Eighty-eight new species are added, bringing the county total to 242.

62. Trehan, K. N. 1938. *Two new species of Aleurodidae found on ferns in greenhouses in Britain (Hemiptera).* Proc. Roy. Ent. Soc., B **7**, Pt. 9.

The scope of this paper is covered by the title. The two new species are *Aleuroplatus kewensis* and *Trialeurodes williamsi*.

63. Trehan, K. N. 1940. *Studies on the British white-flies (Homoptera, Aleyrodidae).* Trans. Roy. Ent. Soc., **90**, 575-625.

An account of the systematics and biology of thirteen species of *Aleurodidae* (white flies) found in Great Britain, with keys for the separation of species in both pupal cases and adults. Notes are also given on parasites.

64. WILLIAMS, C. B. 1937. *The migrations of day-flying moths of the genus* Urania *in tropical America.* Proc. Roy. Ent. Soc., **12**, 141-147.

In parts of Central and the northern half of South America conspicuous day-flying moths of the genus *Urania* make very definite migrations and are frequently recorded, particularly in the neighbourhood of the Canal zone where observers frequently pass them on board ships. This paper is a summary of the information available for two species, one found chiefly in the east, Brazil, the Guianas and Trinidad, and the other ranging from southern Mexico, through Central America to Columbia and Ecuador. Maps and diagrams are given showing the geographic and seasonal distribution of the flights. There is some evidence of a return flight in parts of Central America, but the records are rather confused.

65. WILLIAMS, C. B. 1935. *British immigrant butterflies and moths.* Booklet **E.57,** British Museum (Natural History).

A popular account of the immigration of butterflies and moths into Great Britain, published by the Natural History Museum in London at a low price (ninepence) with five coloured plates, in order to interest the general public in the problem and to get them to send in records of migration to us for study. The first edition of 1,000 copies were printed in October, 1935 and sold out in six months, and a second edition, now out of print, was published in April, 1936. It is hoped that a third edition will be printed now that the war is over.

66. WILLIAMS, C. B. 1937. *Butterfly migrations in the tropics.* Booklet **E. 58,** British Museum (Natural History).

A popular account of the migration of butterflies in the tropics, published by the Natural History Museum in London with five coloured plates, with the object of interesting the general public in the subject and obtaining records from different parts of the world.

67. WILLIAMS, C. B. 1938. *Recent progress in the study of some North American migrant butterflies.* Ann. Ent. Soc. of America, **31,** 211-239.

An account of the increase in our knowledge of ten of the most important North American migrant butterflies since the summary published in C. B. Williams's "Migration of Butterflies" in 1930. Considerable information is given about the migrations of the Monarch butterfly and particularly its spring flight to the north and hibernation in Florida and California. In the case of the Painted-Lady butterfly (*Vanessa cardui*) maps are given showing the distribution of recorded abundance in four years 1924, 1926, 1931 and 1935. In the intervening years, the insect was extremely rare throughout the whole country. In the case of the Great Southern White (*Ascia monuste*) which moves on a very large scale along the Atlantic coast of Florida, there is a suggestion of a change in the direction of the movement from north to south. For fuller information on this, see publication 78.

68. WILLIAMS, C. B. 1938. *The migration of butterflies in India.* J. Bombay Nat. Hist. Soc., **40,** 439-457.

An account of what is known of the migration of butterflies in India with a map showing the distribution of the records, and a list of all the known migrant species with the records of their flights classified according to the month of the year and the duration of the flight. The majority of the records are from Southern India, Madras and Bombay, and then in the extreme north along the Himalayas. In the latter area there appears to be some evidence of a flight up the mountains in the spring, and possibly a return flight in the autumn. Just over fifty species have been recorded migrating.

69. WILLIAMS, C. B. 1938. *The migrations of the cabbage white butterfly* (Pieris brassicae). Proc. VII. Internat. Congr. Entom., 482-.493.

A summary of the movements of cabbage white butterflies with particular reference to Central and Western Europe, but not dealing in detail with Great Britain. Maps and documents show that the recorded flights are chiefly at the end of July and the beginning of August, and throughout Germany, Austria and Western Czechoslovakia and chiefly in a southerly direction, from which it would appear that they originate somewhere in Scandinavia or the Baltic area. In an Addendum there is a record of a southerly movement in Sweden which confirms this conclusion.

70. WILLIAMS, C. B. 1939. *Records of butterfly migration in Africa (Lepidoptera).* Proc. Roy. Ent. Soc., A. **14**, 69-74.

Twenty records of insect migration in different parts of Africa, sent in by correspondents and published to provide information on the movements of butterflies of this continent.

71. WILLIAMS, C. B. 1939. *An analysis of four years captures of insects in a light trap.* Part 1: *General survey; sex proportion; phenology; and time of flight.* Trans. Roy. Ent. Soc., **89**, 79-132.

A light trap of approximately 300 c.p. was exposed in the fields at Rothamsted Experimental Station, almost every night from March, 1933 to February, 1937. The light was about 3 feet 6 inches from the ground.

The total number of insects captured in each of the four years were: 109,344; 103 362; 399,006; and 242,822. The arithmetic mean catches per night were 310, 287, 1,102 and 728 respectively, but the geometric means, which are believed to give a better indication of comparative abundance, were 37, 53, 54, and 64. The highest catch in a single night was 73,100 on the 30th June, 1935.

On the geometric mean basis the highest average catch was in July (723 insects) and the lowest in February (4.2 insects) on an average of all four years.

Diptera constituted 86.7 per cent. of the catch. Lepidoptera 10.3 per cent. while all other insects only constituted 3 per cent. The distribution of all orders in the different months is discussed more fully.

Among the Lepidoptera 256 species of Macrolepidoptera were captured, which is just over one-third of the known British species. Several species were new to the local fauna. There was practically no evidence that the trap markedly reduced the population except possibly in one *Geometrid* moth.

A light trap on a roof at a height of 35 feet (10.6 metres) caught several species of Noctuidae which were absent or rare in the lower trap.

Seventy-four species of Heteroptera were captured, of which 57 were Capsidae. This is almost one-third of the known British species of Capsidae.

The majority of Lepidoptera come to the trap with a considerable excess of males over females, but this is not an absolute rule, and some species give an excess of females. The sex proportion in a number of species is listed

In the Tipulidae (Diptera) the sex ratio varied from species to species and even the closely related species *Tipula paludosa* and *T. oleracea* give opposite results.

In Chrysopidae and Hemerobiidae there is an excess of females and in the Heteroptera an excess of males.

Certain species of Lepidoptera are shown to vary considerably in the sex ratio from year to year and there is also slight evidence of different sex ratios in the individuals captured from different broods.

The proportion of females caught increases in many species during the course of the brood.

In the Lepidoptera there is evidence in many species that a higher proportion of females are caught before midnight than after. The same appears to be true of the Neuroptera, but in the Diptera some species show a higher and some a lower proportion before midnight.

In a trap placed on a roof at a height of 35 feet from the ground more species and individuals of Noctuidae were captured than near the ground, and the individuals included a considerably higher percentage of females. The difference was more marked in some species than in others.

When the trap was removed from the roof and placed on a tripod immediately above the ground trap, but at the same height as the roof, the numbers of individuals of Noctuidae fell very considerably, but the relatively high percentage of females in the captures remained.

It was found that in certain Noctuidae females were in a higher percentage on nights when the moths were rare and relatively much fewer when the moths were common. Also in all the species of this family there was on an average a lower proportion of females caught in the common species than in the rarer ones.

The sequence of broods in a number of species of Lepidoptera is discussed and it is shown that in general first dates were early in 1933 and late in 1935 and 1936.

There is slight evidence that the Noctuidae have a lower variability of date than the other families and also slight evidence of a seasonal change in variability.

The date of first appearances, usually taken for phenological purposes, has the advantage of convenience but is more variable than other points later in the brood, such as, for example, the date on which 25 or 50 per cent. of the total captures have appeared.

Work on the time of flight of insects at night, on which two years' data had previously been published, is reviewed in the light of two more years' work. Nearly all previous conclusions are found to hold. For all four years on a log. basis the highest catch is in period 1 and the lowest in period 7. Evidence is, however, brought forward to indicate a seasonal change of distribution.

The time of flight of a number of species of Lepidoptera is discussed and it is found that there is a tendency for the peak flights to occur in periods 2, 5 and 8 of the 8 equal periods into which the flight was divided.

In the Neuroptera, the Hemerobidae tend to fly into the trap early in the night and the Chrysopidae later.

72. WILLIAMS, C. B. 1939. *Some records of butterfly migration in America.* Proc. Roy. Ent. Soc., A, **14**, 139-144.

Details of thirteen records of the migration of Lepidoptera sent in from correspondents in North, South and Central America.

73. WILLIAMS, C. B. 1939. *Some butterfly migrations in Europe, Asia and Australia.* Proc. Roy. Ent. Soc., A, **14**, 131-137.

Details of fifteen records of migration of Lepidoptera sent in by correspondents from Europe, Asia, and one from Australia. Included in these are records of the cabbage white butterfly and silver Y moth (*Plusia gamma*).

74. WILLIAMS, C. B. 1940. *A note on the statistical analysis of sentence length as a criterion of literary style.* Biometrika, **31**, 356-361.

A resemblance is pointed out between the form of frequency distribution of the number of insects caught on different nights in a light trap and the number of words in successive sentences as written by different authors. In both cases the curve as represented by actual numbers of insects or of words is extremely skew, but when the log. of the number of words or of insects is used instead, the curve becomes normal and symmetrical. This transformation greatly facilitates comparison between different samples, and examples are given from the works of three different authors to illustrate this point. This form of curve has recently been designated the Lognormal curve.

75. WILLIAMS, C. B. 1940. *An analysis of four years captures on insects in a light trap.* Part 2: *The effect of weather conditions on insect activity, and the estimation and forecasting of changes in the insect population.* Trans. Roy. Ent. Soc., **90**, 227-306.

The analysis is based on four years captures in a light trap at Rothamsted Experimental Station. The trap was working on 1,407 nights between March, 1933 and February, 1937 and caught altogether about 850,000 insects. An account is given of the normal weather conditions of the district and also of the weather during the four trap years.

The sources of error were reduced as far as possible, and it was found necessary to deal with changes in the catch in geometrical or logarithmic proportion.

The catch is dependent chiefly on the two factors of activity and population, and, of course, only measures the positively phototropic nocturnal insects.

The analysis of the individual effect of each weather factor is made more difficult by the close correlation which exists between many of the weather factors themselves.

The first analysis was a simple comparison of the weather conditions on nights of high and low catch. On the good nights the minimum and the grass minimum temperatures of that night and the maximum temperatures of the previous day were all higher than on poor nights; the wind was also calmer; the moon closer to new moon than to full, and the barometer high. Rain during the previous day time is associated with low catch, but rain during the night occurs with equal frequency with high as with low catch. Relative humidity also appears to be more or less similar in both series.

A short account is then given of the statistical method of regressions and

it is shown that activity is most likely to be correctly estimated by using as a basis of calculation the difference between successive days in both catch and weather conditions. The effect of minimum temperatures, considered alone, is that a change of 1° F. is associated with a change of log. catch of about 0.060 or, in other words, the catch is doubled by an increase in minimum temperature of 5 F. (or just under 3°C.). There is no evidence from the data available that this figure alters with the season, the differences found from month to month are irregular and not outside the limits of non-significant variation. Results for Lepidoptera only and Hemiptera only give values which do not differ significantly from the value for total insects.

The effect of maximum temperature alone is smaller than that of minimum temperature and the average effect (over the four years) is that 1° F. change is associated with 0.042 change in log. catch, or the catch is doubled with a rise of about 7° F.

The grass minimum alone (calculated from six months results) shows a regression of 0.030. The regression on daily range of temperature (from three months) is only 0.004 which has no significance.

Relative humidity at 9 p.m. shows a small but probably significant regression of about 0.008 change in catch produced by 1 per cent. change in humidity.

Insects fly later on cloudy nights, probably owing to the slow fall in temperature. The effect of fog is uncertain ; usually it occurs on cold nights with very poor catch, but one very foggy night in September, 1933 gave high catches in the family *Noctuidae*.

The catch is lower at full moon than at new moon and there are asymmetries in the effect that can be explained by similar asymmetries in the times of rising and setting on the moon.

Wind force was divided into six artificial groups, the lowest being " dead calm " and the highest "wind over 20 m.p.h. " The effect is complicated by the fact that the windy nights are warmer than the still nights, particularly in the winter. When the method of difference between successive days is used the effect of a change of one group was to alter the log. catch by 0.095 (other factors being neglected).

The effect of barometric pressure is complicated and difficult to understand. Catch is low with low barometer, and high with high barometer unless pressure is falling ; in this latter case the catch is distinctly lower. If the direction of movement is neglected, the average effect of a rise of 1 inch in the barometer is to add 0.668 to the log. catch. The catch is therefore doubled by a rise of 0.48 inches (1.14 centimetres.)

There is no evidence of the effect of thunderstorms on the total catch of all insects, but slight indication that moths of the family *Noctuidae* are more abundant during thundery weather.

The simultaneous analysis of several factors acting together show differences from some of the above results owing to correlation between the weather conditions themselves. Analysis of 9 p.m. temperature and humidity, expressed as Relative Humidity, Absolute Humidity and Saturation Deficiency, shows no advantage to be gained by using one method rather than another.

With partial regressions of catch on the minimum temperature of several nights preceding the catch, it was found that the previous night has about one-fifth of the effect of the current night, but the night before that had on an average no effect.

When the maximum and minimum temperatures and wind were taken simultaneously the regressions of each were 0.023, 0.070 and 0.144 respectively.

For the year 1933 the simultaneous effect of the above three factors plus 9 p.m. relative humidity was calculated and the regressions were 0.016, 0.065, 0.121 and 0.006.

It is possible to correct the mean catch for each month for the effect of its departures from the normal in temperatures, wind, etc., thus getting a value for what the catch would probably have been if all conditions had been normal for the month. The differences then remaining are due to population effects. These values have been calculated for the 48 months in which the trap was running.

The relation of these values to the rainfall and minimum temperature of the three previous months has been caculated and two regression formulae obtained, one for winter and one for summer, from which the population

changes can be estimated from a knowledge of previous weather conditions only. Rainfall is most important in summer and temperature in winter.

Thus a beginning has been made in the problem of measuring the variations in abundance of insects and in forecasting this from a knowledge of the weather conditions. So far it has only been described for the total population of all insects but it will later be extended to single species.

76. WILLIAMS, C. B. 1940. *The numbers of insects caught in a light trap at Rothamsted during four years, 1933-37.* Proc. Roy. Ent. Soc., A, **15**, 78-80.

As the insects caught in the light trap at Rothamsted during the four years, 1933-37 have been used in a series of discussions on the effect of weather conditions on insect activity, it was decided to publish the complete data of the numbers caught each night in the four years, so as to make it available for other workers. The trap was working on 1,407 nights and captured a total of just over 853,000 insects. The insects were approximately 87 per cent. Diptera, 10 per cent. Lepidoptera, and 3 per cent. of the remaining orders.

77. WILLIAMS, C. B. 1940. *On "type" specimens.* Ann. Ent. Soc. America, **33**, 621-624.

A discussion on the value of the designation of "type" specimens in Entomology for the prevention of difficulties of nomenclature. It is argued that one type individual only is necessary, as the object of the "type" specimen is to eliminate doubt in naming, and if two or more "type" specimens are allowed doubt is again introduced.

78. WILLIAMS, C. B., COCKBILL, G. F., GIBBS, M. E. and DOWNES, J.A. 1942. *Studies in the migration of Lepidoptera.* Trans. Roy Ent. Soc., **92**, 102-283.

The report gives a general account of progress along various lines in the study of the migration of Lepidoptera particularly in the last ten years since the publication of Williams' "Migration of Butterflies" in 1930. Among interesting early records of butterfly migration in an account of one seen in the year 1508 near Calais in France.

A detailed history of the abundance each year for over 100 years is given for about forty of the principal British immigrant butterflies and months. A geometric scale is adopted and all species are graded each year in one of six levels of abundance, the scale for each species being proportional to its maximum occurrence. As much as possible of the early literature has been examined and the records are believed to be sufficiently complete to justify discussion. The monthly distribution of most species has been worked out and in one or two it has been possible to show a relation between early appearance and abundance during the summer.

An analysis of nearly 400 records of insects from ten lightships off the east and south-east coasts of Britain gave a list of 140 species of Lepidoptera on which 35 occurred on several occasions or in numbers which make it unlikely that their presence was accidental. Thirteen of these were known or suspected migrants. Others high up in the list were *P. meticulosa*, *A. monoglypha*, *E. similis* and *A. c-nigrum*. The flights were predominantly to the north and north-west from May to mid-August and to the east or south-south-east after mid-August.

Mr. and Mrs. Hodges of Florida made an almost continuous daily watch on the movement of butterflies for nearly two years. Their results are analysed. They show: (1) a regular migration of *A. monuste* each year, at first to the south and then a sudden reversal of direction during May or June; (2) an almost continous southerly movement of *P. eubule* and *T. lisa* at all times of the year; (3) regular movements to the north in spring, and/or autumn movements to the south in several other species including *Danaus plexippus* and *D. berenice*, *Dione vanillae*, *Papilio cresphontes* and *Eudamus protemus*.

The migrations of *D. plexippus* are discussed from several points of view. A study of geographical variations in America indicates a northerly migratory race in North America; a southerly migratory race in South America, south of the Amazon; and a non-migratory race between these two in the northern portion of South America and many of the West Indian islands.

Downes observed the overwintering of *D. plexippus* in California and considers that most hibernating areas are very close to the sea and nearly all

suitable spots are occupied to some extent. The males are sexually mature on emerging from the chrysalis in the autumn, pairing taking place throughout autumn, winter and spring; but the females do not normally mature eggs till the spring.

A large number of new records of migration for North and South America are discussed. A full list of the British and European records of appearance of *D. plexippus* is given, and a number have been examined, all except one of which are of the Northern American race.

Summaries are given of the present information on the migration of several other butterflies from America, Europe, Africa and Australia. A full account is given of recent extensive migrations of *Pieris brassicae* in England, including a flight at Harpenden that continued to the south for over three weeks. New records of *V. cardui* in West Africa indicate a definite migrating season south of the desert belt in September and October. New records are summarised for *Glycestha aurota*, *G. creona*, *G. java*, *C. florella* and several others.

An account is given of some recent experiments in marking butterflies. Practically no recoveries have been made at a distance but much can be learnt from the rate of disappearance of the marked individuals from the locality of marking. A satisfactory technique is described. It is important to be able to distinguish individuals of the same species marked on the same date.

Orientation might possibly be by wind, sight or perception of the earth's magnetic field. These three are discussed. It is shown that an individual insect might determine the direction of the wind without the use of sight, but there is no evidence that the direction of the wind determines the direction of migration. Recent work on orientation by sight is discussed in relation to migration. Experiments on young locusts showed no evidence of appreciation of a powerful magnetic field.

Evidence for the occurrence of a return flight in migrant Lepidoptera is shown to be increasing. The question of the fundamental difference between migrations with and without a return flight is reviewed, and the evolutionary difficulty of the persistence of migration without a return flight is emphasised.

A significant positive correlation between the occurrence in unusual numbers of *V. cardui* in Europe and North America is shown to exist. This supports the similar results previously obtained from *C. lineata*.

Intercorrelations between 35 British immigrant Lepidoptera have been calculated and discussed. The average correlation is slightly positive (+0.12). By sorting the species it has been possible to find several groups the members of which are positively correlated within their own groups, but usually negatively correlated with other groups (Table 34). The first of these is quite definite and contains fifteen closely associated species. The second is less definite. Group 7 contains five species and Group 8 the three *Pieris* species. To a certain extent the grouping follows the geographical range of the species. The average frequency of the principal groups each year for 78 years shows no evidence of periodicity.

A classification is suggested of the density of any flight as measured by the number of insects crossing a definite front in a definite time. This is a series of seven grades in which the numbers are in geometric proportion.

The bibliography includes all references to the migration of butterflies that have been traced in the past ten years and which are not included in the previous bibliography given in Williams's "Migration of Butterflies," 1930.

79. WILLIAMS, C. B. 1943. *Studies in wild populations.* Nature, **151**, 71.

A short account of the discussions of problems relating to the wild populations at a joint meeting of the Royal Entomological Society and the Genetical Society.

80. WILLIAMS, C. B. 1943. *Birds and butterflies.* Nature, **151**, 173-175.

A review of the recent work by Professor G. D. H. Carpenter and Mr. C. F. M. Swinnerton on the extent to which birds eat butterflies, and on the selection which they make between supposedly distasteful and palatable species.

81. WILLIAMS, C. B. 1943. *A method of collecting and storing without pressure insects and galls attached to leaves.* Proc. Roy. Ent. Soc., A. **18**, 1-2.

The paper gives a short illustrated account of a method of storing leaves to which insects are attached in a special form of pill-box to protect them from pressure.

82. WILLIAMS, C. B. 1943. *A safe method of measuring the wings of se butterflies.* Proc. Roy. Ent. Soc., A, **18**, 3-5.

A simple optical device is described by which measurement of the length of wing of pinned insects can be made without removing the glass from the box in which they are contained. The method consists essentially of two similar glass scales mounted about an inch apart by means of which the error of parallax can be avoided.

83. WILLIAMS, C. B. 1943. *Notes on some Monarch butterflies captured in Great Britain.* Entomologist, **76**, No. 956.

A list of nine records of the monarch butterfly in Great Britain, additional to the complete list of occurrences given in paper No. 78.

84. WILLIAMS, C. B., FISHER, R. A. and CORBET, A. S. 1943. *The relation between the number of species and the number of individuals in a random sample of an animal population.* J. Anim. Ecol., **12**, 42-58. Summary of Part 2, by C.B. Williams.

Extensive data on the capture of about 1.5000 Macrolepidoptera of about 240 species in a light trap at Harpenden is analysed in relation to Fisher's mathematical theory and is shown to fit extremely closely to the calculations. The calculations are applied first to the frequency of occurrence of species represented by different numbers of individuals—and secondly to the number of species in samples of different sizes from the same population. The parameter " α " which it is suggested should be called the " index of diversity," is shown to have a regular seasonal change in the case of the Macrolepidoptera in the trap. In addition, samples from two traps which overlooked somewhat different vegetation are shown to have " α " values which are significantly different.

It is shown that, provided the samples are not small, " α " is the increase in the number of species obtained by increasing the size of a sample by e (2.718). A diagram is given (Fig. 8) from which any one of the values, total number of species, total number of individuals and index of diversity (α), can be obtained approximately if the other two are known. The standard error of α is also indicated on the same diagram.

85. WILLIAMS, C. B. 1943. *Area and number of species.* Nature, **152**, 264.

A large number of records of species of plants in certain areas of known size were collected and studied in particular reference to the number of species and the area of the locality. The areas ranged from two square inches up to the total land surface of the globe, and the number of species from two up to approximately 200,000. By means of a double Logarithmic scale, the information for about 200 localities is given diagramatically and it is suggested that the relation between area and number of species is governed largely by Logarithmic series when the area is small (up to about three or four acres). within which area there is a chance of uniform ecological conditions. From the limits of this area to the limits of the continental areas of two or three million square miles, the rate of increase in number of species with area is more rapid, and this is probably due to the increasing ecological diversity of the area as it gets bigger. When continents are added together, to produce a flora of the whole world, there is a still more rapid increase in the number of species with area, due to the fact that we are now putting together areas of different geological and evolutionary history.

86. WILLIAMS, C. B. 1944. *The numbers of publications written by biologists.* Ann. Eugen., **12**, 143-146.

In investigations on the relative numbers of species of insects with different numbers of individuals, it was found that the mathematical series so obtained closely fitted a Logarithmic series. The present paper shows that the number of publications by biologists in one year as exemplified by the contents of the Review of Applied Entomology and the Review of Applied Mycology also fit to the same Logarithmic series.

87. WILLIAMS, C. B. 1944. *Some applications of the Logarithmic series and the index of diversity to ecological problems.* J. Ecol., **32**, 1-44.

The paper describes the application of Logarithmic series to a number of problems of the division of individuals into species and of species into genera. The series, first suggested by R. A. Fisher in this connection is:

$$n_1 \quad ; \quad \frac{n_1}{2}x \quad ; \quad \frac{n_1}{3}x^2 \quad ; \quad \frac{n_1}{4}x^4$$

where n_1 is the number of groups with one unit and x is a constant less than unity. Unlike the hyperbolic series, which has previously been considered to apply to some of the cases discussed, the Logarithmic series is convergent; both the number of groups (e.g., species) and the number of units (e.g., individuals) can be summed. When several samples are taken from a population containing a number of species it is found that the ratio n_1'x is constant and, as it is therefore a characteristic of the population, it has been called the Index of Diversity.

The Logarithmic series is found to fit extremely well to a large number of frequency series drawn from insects, birds, butterflies and plants, except that there is a slight tendency for the calculated n_1 to be below the observed. It also fits well, sometimes extremely well, to the number of genera with different numbers of species in standard classifications of groups of both animals and plants. The conception of the index of diversity is applied to problems of the number of species of plants on different areas, and to the comparison of floras of different areas with interesting results. A classification is given of the 171 families of dicotyledons according to their index of diversity to stimulate a discussion as to which may be the factors which bring about differences and resemblances in this index. In general, the families with large numbers of species and genera have large index of diversity, but there may be a very big range of index in families of approximately the same size.

88. WILLIAMS, C. B. 1945. *Occurrence of* Vanessa cardui (*Lepidoptera*) *at sea off the West African coast.* Proc. Roy. Ent. Soc., **20**, A, 4-5.

An account of observations made during a sea voyage down the west coast of Africa in September, 1943, when painted lady butterflies were observed at sea, more than a hundred miles from land, over a period of nearly a week and over a distance of nearly 1,500 miles from the first one seen off Morocco to the last one seen just north of Sierra Leone. Previous records of the abundance of painted lady along this coast are nearly all in the months of September and October.

89. WILLIAMS, C. B. 1945. *Index of diversity as applied to ecological problems.* Nature, **155**, 390-392.

A short reply to a letter by Mr. E. W. Jones in "Nature" criticising certain results obtained in the number of plants on different areas of land in relation to the Logarithmic series. It is shown from the data available that in all probability on the area studied the plants were strongly aggregated and therefore the areas used for sampling were not large enough to give a fair sample of the population.

90. WILLIAMS, C. B. 1945. *Notes on the fat content of two British migrant moths* (*Lepidoptera*). Proc. Roy. Ent. Soc., A., **20**, 6-13.

Recent work in the United States on a migrant leaf-hopper shows that the amount of fat food reserve in the body is related to the distance flown on migration. A very large number of Silver-Y moths and some other species were captured at a searchlight on the south coast of England in August, 1944, and the opportunity was taken to extract the fat from the dried bodies of a number of specimens, to get figures for the fat content and particularly the variation from individual to individual which had not been possible in the case of the small leaf-hoppers in America. Diagrams are included showing the frequency distributions of the weights of the abdomen and the weights of fat. This reached about 45 per cent. of the total weight of the abdomen in 48 males and 50 females, and about 33 per cent. of the total weight of the body excluding wings, but there was very considerable variation, some specimens containing 70 per cent. of the abdomen weight, and 60 per cent. of the total weight of the body. Results are also given for another moth, *Phlogophora meticulosa*, for comparison.

91. WILLIAMS, C. B. 1945. *Evidence for the migration of Lepidoptera in South America.* Rev. Ent., **16**, 113-131.

Information is given on 84 directional flights of Lepidoptera in South America, some observed by the writer and others reported from published and unpublished sources. The whole is given as evidence of extensive migration of Lepidoptera in South America.

92. WILLIAMS, C. B. and BEALL, G. 1945. *Geographical variations in the wing length of* Danaus plexippus (*Lep. Rhopalocera*). Proc. Roy. Ent. Soc., A., **20**, 65-76.

In association with Dr. G. Beall of Canada, a study was made of the variability in wing length of the migrant butterfly *Danaus plexippus*. The wing lengths of over 2,000 specimens were measured, and the paper gives an account of the variability in wing length according to the geographical distribution of the different races in North and South America and of different localities in North America. The object was to see if it would be possible to identify populations of similar origin by average wing length and variability. It was found that approximately 50 individuals must be examined in order to be able to compare differences of 1 mm. In general there was some evidence that the species was smaller near the Equator than either in the extreme north or south, and smaller in the west than in the east.

93. WILLIAMS, C. B. 1945. *Recent light trap catches of Lepidoptera in U.S.A., analysed in relation to the Logarithmic series and the index of diversity.* Ann. Ent. Soc. America, **38**, 357-364.

Walkden and Whelan in 1942 published data on the catching of about 500,000 moths on 300 species in light traps in six localities of Kansas and Nebraska. The data provided by this publication has been analysed in relation to the Logarithmic series and has been found to fit closely, with the exception that the observed number of rare species with one two or three specimens only is in general above that collected. The fit is not so good as for similar data obtained in Great Britain. In one or two cases the catch was dominated by very large numbers of one or two species. In one locality two species made up over 90 per cent. of the total captured. It is possible that this may account for the generally poorer fit.

BEE DEPARTMENT

By C. G. Butler

In January, 1939, on the resignation of Mr. D. M. T. Morland who had been in charge of the Bee Section, a Sub-Department of the Entomological Department, since it first came to Rothamsted from Cambridge in 1921, Dr. C. G. Butler was appointed Entomologist in Charge of the Bee Section. A few months later Mr. P. S. Milne was appointed to the Section to carry on and extend the work commenced by Dr. H. L. A. Tarr on brood diseases of the honeybee, Dr. Tarr having resigned some months before Mr. Morland. At the outbreak of the war, therefore, the staff of the Section as it then was, consisted of Dr. Butler, Mr. Milne and Mr. A. C. Rolt who had been the Section's Apiarist since 1921. During the period under review the following people have also worked for a year or more in the Section, Dr. G. F. Cockbill, Miss P. Schiele, Dr. A. C. Fabergé, and Mr. E. P. Jeffree.

In 1944 the Bee Section received its autonomy from the Entomological Department and became an independent Bee Department. The following persons staff the Department today; Dr. Butler, Mr. Milne, Miss A. D. Synge who replaced Mr. Jeffree when he resigned in 1944 to take up a beekeeping post at the North of Scotland College of Agriculture, Mr. N. Ellement, Chief Apiary Assistant, succeeding Mr. A. C. Rolt who resigned in 1944, to become Beekeeping Instructor to the County of Somerset, Mr. J. Clifford, Junior Apiarist, two girl Laboratory Assistants, and the Department also has the services of a Secretary-Laboratory Assistant, Mr. A. Wafa, of Cairo University, joined the Department as a Ph.D. student of London University in 1945.

The Bee Department differs from other Departments at Rothamsted in that, although research work is the primary objective of its members, it also carries out a great deal of advisory and extension work, thus being brought into closer contact than would otherwise perhaps be the case with the problems both of the growers of fruit and seed crops and of the beekeepers. During the war both the research and the advisory work of the Department have increased very considerably. Members of the Department have also been called upon to serve on various specialist committees such as the Ministry's Bee Disease Advisory Committee and a Sub-committee of the British Standards Institution concerned with the standardisation of beekeeping equipment. In addition, since the retirement of the Ministry's Technical Advisor on Beekeeping, Dr. Butler has been acting as the Ministry's beekeeping expert.

Members of the Department had a good deal to do with the drawing up and application of the Foul Brood Disease of Bees Order, 1942, and have since this Order came into force been responsible for the examination of all sample combs taken, and for organising courses of instruction at Rothamsted for over 300 officers appointed under the Order to examine colonies of bees suspected of being diseased.

As intimated above, the work of the Bee Department during the period under review falls naturally into two main categories, research work and advisory work, each of which may be subdivided as follows :—

1. *Research Work*
   (*a*) Research on the various diseases of the honeybee and her brood.
   (*b*) Pollination studies including examination of the possible dangers to pollinating insects resulting from the use of insecticidal and fungicidal sprays and dusts.
   (*c*) Work on various problems of bee anatomy, physiology and behaviour, on bee husbandry, etc.
2. *Advisory and Extension Work*
   (*a*) Diagnosis of adult bee diseases and of brood diseases in samples of bees and their brood submitted for examination.
   (*b*) Advice to beekeepers and to fruit and seed growers on problems concerned with both the healthy and the diseased bee, pollination, etc.
   (*c*) Lecturing, demonstrating, broadcasting, the preparation of Bulletins and Leaflets, and of illustrated lectures for loan to Beekeepers' Associations, etc., and the elaboration of measures for the control of bee diseases on a national scale.

Various aspects of the work of the Department enumerated above will be discussed briefly in the following pages.

Foul brood disease of bees order, 1942

Almost as soon as war broke out steps were taken to obtain an increased measure of control over bee diseases, particularly of the two diseases usually described as Foul Brood. In this connection a scheme for the control of Foul Brood on a national scale was drawn up and served as the basis for the Foul Brood Disease of Bees Order which was introduced in March, 1942. The introduction of this Order soon led to a very considerable increase in the number of brood combs submitted for examination since the Department became the official laboratory to which all samples of comb have to be submitted in the course of application of the Order. Besides the Order directly effecting a big increase in this side of the Department's work it has also, because it tended to make beekeepers more disease conscious, led indirectly to a considerable increase in advisory work.

The following Tables show the numbers of samples of brood combs and of adult bees examined during the years 1939-1945 inclusive :—

Brood combs examined

Year (Jan. 1-Dec. 31)	Total No. of combs examined	No. of combs with American Foul Brood	No. of combs with European Foul Brood	No. of combs in which other diseases were found	No. of combs in which no diseases were found
1939 ..	270	112	18	45	98
1940 ..	182	90	2	26	64
1941 ..	316	140	16	26	134
1942 ..	1,055	613	13	60	374
1943 ..	1,801	1,161	43	124	478
1944 ..	2,519	1,791	43	136	559
1945 ..	2,244	1,559	30	104	567
	8,387	5,466	165	521	2,274

(*Note.*—More than one disease may be present in the same comb, hence the total of columns 2-5 is usually greater than the figure in column 1.) The effect of the introduction of the Foul Brood Disease of Bees Order in March 1942 was, as shown above, to cause a great increase in the number of sample combs sent for examination each year, this increase resulting from a widespread search for these diseases in most districts in England and Wales.

Samples of adult bees examined

Year : (Oct. 1-Sept. 30)	Total No. of samples	No. samples with Acarine disease	No. samples with Nosema disease	No. samples with Amoeba disease	No. samples in which no diseases were found. (Paralysis not counted as a disease)
1939-40 ..	—	—	—	—	—
1940-41 ..	194	48	12	0	134
1941-42 ..	1,310	298	90	0	922
1942-43 ..	2,317	559	56	18	1,693
1943-44 ..	1,545	481	11	18	1,035
1944-45 ..	1,224	344	32	8	837
	6,590	1,730	201	44	4,621

[*Note.*—More than one disease may be present in the same sample of bees, hence the total of columns 2-5 may be greater than the figure in column 1.]

The incidence and distribution of adult-bee diseases

Two entirely objective surveys to determine the incidence and distribution of adult-bee diseases in England and Wales were carried out during the winters 1941-42 and 1943-44. The first of these surveys showed that at least one in five of all colonies of bees in England and Wales was at that time suffering from Acarine disease. Further, the results showed that there were areas of low percentage infection in Cheshire and in the east Midlands, and of high infection in the south and south-west.

Nosema disease was also found to be widely distributed, although not nearly so common as Acarine disease. Amoeba disease is widespread, but relatively rare.

The results of the 1943-44 survey largely confirmed those of the earlier survey and also indicated that the position with regard to Acarine disease, taking the country as a whole, had not deteriorated since the spring of 1942, but, if anything, showed some signs of improvement. A paper on the incidence and distribution of adult bee diseases in England and Wales, based on data collected in these two surveys and also from routine examination of samples of bees submitted for diagnosis, has been published (10).

Acarine disease

Comparative tests of methyl salicylate, safrol, nitrobenzene, and various other substances, particularly pine-oil derivatives, for the treatment of acarine disease have been carried out. One substance in particular, terpineol, was found to be of considerable value as a poison to *Acarapis woodi* and certain other mites. It was further shown that the effect of this heavy fraction of crude pine oil on the bee and on the mite was markedly differential : that is, that the exposure time required to kill the mite is much less than that required to harm the bee in any way. The dosage when applied to a colony for the treatment of acarine disease is, apparently, not very critical (5).

Nosema disease

During 1940 a colony of bees that was heavily infected with *Nosema apis* was kept under observation. Marked bees from a healthy colony were introduced into the infected colony at intervals during June and July. Samples of these marked bees were taken at regular intervals and examined for the spores of *Nosema*. The degree of infection fell from 100 per cent in April, when the first examination was made, to zero in August, when no more infected bees could be found. This result is in agreement with previously made observations.

During the period under review a series of experiments have been conducted to test the effects of various drugs, including sulphonamides, on the development of *Nosema* disease in bees kept in cages and infected with known concentrations of viable *Nosema* spores. None of the substances so far tested has fully satisfied the condition that it should be effective in checking the course of the disease and, at the same time, be harmless to the bees themselves. This is in agreement with conclusions reached in the U.S.A. as the result of trials with sulphonamides for the control of this disease.

Bee paralysis

Work has shown that in many instances bee paralysis should be regarded as a complaint, often due to a dietary upset, rather than as a disease caused by some pathogenic organism. Various forms of paralysis have been described, only one of which can be considered a disease in the strict sense of the term. The nature and cause of many of these forms of paralysis were investigated, and several new types described (7).

Poisoning of honeybees by insecticidal and fungicidal sprays

A considerable amount of work has been done on this subject. Prior to the introduction of D.D.T., work upon which has been commenced and tends to show that this new insecticide is probably less harmful to adult bees than had been anticipated, the only ingredient in the spray mixtures commonly employed in this country that causes serious poisoning of bees is arsenic in the form of lead or calcium arsenate. It was found that bees become poisoned in one of two ways. Either by collecting their drinking water from the foliage and trunks of sprayed trees or surrounding herbage, or by the collection of pollen contaminated with arsenic. Bees collecting the contaminated drinking water usually die in the field, whereas those collecting contaminated pollen often regain the hive and both the adults and their brood become poisoned when they eat the pollen. It has been found that the addition of 1 per cent lime sulphur to arsenical spray mixtures is sufficient to repel honeybees from collecting their drinking water from this source. The other, more serious, form of arsenical poisoning can only be prevented by growers refraining from spraying open blossom with spray mixtures containing arsenic (15).

Spread of Foul Brood via wax foundation

In 1939 an experiment was set up to determine whether Foul Brood could be transmitted by means of wax taken from infected colonies being sent to the manufacturers, processed and redistributed as wax foundation. A quantity of wax was obtained by very gentle heating from combs heavily infected with both American and European Foul Brood. This was turned into foundation by one of the manufacturers who employed their usual technique. This foundation was given to a number of healthy nuclei and their subsequent needs in the shape of further combs were supplied from this source. Although these nuclei were built up to colony strength and have been kept under close observation since the summer of 1939, no trace of Foul Brood has been detected in them. It appears fairly safe to conclude, therefore, that there is little danger of Foul Brood being disseminated via infected wax sent to the manufacturers and, after processing, being distributed to beekeepers as wax foundation.

Bald-headed brood

Wax-moth larvae (*Achroia grisella* Fabr.) have from time to time been found lying alongside pupal honeybees contained in cells from which the normal capping was missing. Masses of faecal pellets of the wax-moth larvae were sticking to the pupae, many of which developed with deformed legs and wings. Perforations in the cell walls made by the larvae in their wanderings from cell to cell were seen. The large number of faecal pellets and the absence of damage to the mid-rib of the comb suggested that the "bald-headed" appearance was due to the cappings having been eaten away from below by the wax-moth larvae (19).

Sulphonamides and Foul Brood

During 1944 a preliminary test of sulphapyridine for the treatment of colonies of bees suffering from American Foul Brood, reported by a beekeeper (Mr. C. A. Ekins, of Surrey) to have given successful results against this disease, was carried out. It appeared from this preliminary small-scale test that the progress of the disease was in fact arrested by the use of sulphapyridine (23). More extensive tests with various sulphonamides were carried out during 1945 for the elimination of both American and European Foul Brood from infected colonies. The tests for the control of American Foul Brood yielded highly promising results. This work is being continued and more exhaustive trials in different parts of the country are planned for 1946.

Brood diseases—general

Papers on the incidence and distribution of brood diseases have been published (20, 21, 22). A number of unpublished observations and experiments have been made on the various brood diseases such as American Foul Brood, European Foul Brood, Sac Brood, Addled Brood and Chalk Brood.

A method of rearing individual bee larvae by hand, first described by von Rhein in 1933, has been developed and improved.

Losses, particularly those due to the attacks of fungi after the larvae had been reared successfuly to the pupal stage, were heavy at first but these have been substantially reduced as a result of improvements in the technique and familiarity with the requirements of the larvae.

This technique will be of value in the study of the initiation and development of the various brood diseases. It will also be of value for observations on the nutrition of the healthy larvae, on the evaluation of the nutritive value of pollens and pollen substitutes, and in similar problems in which it is desirable to keep larvae under closer observation than is possible in the hive.

Investigations on the nature of the complaint known as " Addled Brood " have been carried out during the period under review, but no definite conclusions have yet been reached. Work on various problems connected with both American and European Foul Brood has similarly been carried on.

Pollination studies

A considerable amount of work has been carried out in attempts to estimate the value of the honeybee and other insects for the pollination of various fruit and seed crops. It has been found that, contrary to statements frequently made, the honeybee does assist in the pollination of Red Clovers to a very considerable extent (6). Evidence has also been collected to show that the honeybee plays a most important part in the pollination of many other crops (8).

The behaviour of populations of various pollinating insects, including the honeybee, when foraging, has been studied in some detail. It has been found that, contrary to expectation, the honeybee (and some other pollinating insects studied, including the bumblebees) does not wander at random over a crop when seeking nectar and pollen, but restricts its activities to a small area of the flowers usually some 4-5 yards in diameter. However, if a sufficiently large population of foraging insects is working the crop concerned, another population of " wandering bees " which have not yet become " established " in any particular area, is superimposed on the general population of " established " bees (16). These and other observations have led to considerable changes in the advice given to fruit and seed growers who employ honeybees as pollinating agents, and have made it possible for any grower to determine how many colonies of honeybees of any given strength he will require in order to obtain a maximum set of fruit or seed in any given area (11).

A good deal of attention has been paid to the effects of the various physical and biological factors of the environment upon the flying activities of honeybees (12, 14, 18) since a knowledge of the probable effects of given weather conditions would help to solve some of the problems connected with insect pollination of fruit and seed crops. In order to obtain accurate measurements of the flight activity of a colony of bees throughout the day special bee counters were designed and built. These counters give continuous records of the number of bees entering and leaving the hive throughout the day (17).

Observations on the relationships between honeybee activity and solar radiation (14) and between activity and nectar concentration and abundance (12) have also been made, as have observations on the effects of temperature, humidity and wind velocity, precipitation, etc. A start has also been made in an endeavour to determine the effects of the various physical factors of the environment upon nectar secretion in various species of plants visited by honeybees, and plans have also been made to attempt to determine the effects of various soil constituents.

Work has been carried out during the past few years, and is being continued, in an endeavour to find a reliable and simple method of causing a large and ever-increasing proportion of the foraging bees from any selected colony to visit the flowers of, and thus pollinate, any given crop. Some success has been achieved in Russia, Germany and this country by feeding the colonies of bees concerned with concentrated sugar solutions containing the " scents " of the flowers of the crops which it was deemed desirable that the bees should visit. The feeding in this way of syrup containing " scent " causes many of the young foraging bees to associate the particular " scent " with the presence of desirable nectar and, on leaving the hive on their foraging expeditions, to seek this " scent " in the field, thus finding the flowers which it is desired that they should work. Even should the flowers contain little nectar, observation has shown that the bees will continue to work them for some days, particularly if the feeding of correctly " scented " syrup within the hive is continued. This technique may well prove to be of considerable value to seed growers.

General work. Bee husbandry

Many suggestions have been put forward from time to time with regard to the most suitable type of drinking water for bees. It has been suggested that bees obtain certain salts essential for their well-being by collecting water from sources containing such salts. The whole matter was investigated during 1939 and 1940, and it was found that honeybees were attracted to particular sources of water primarily by their odour, irrespective of what salts the water at these sources contained (3). An automatic drinking fountain was designed (2).

In collaboration with the Electrical Research Association a series of experiments on the electrical heating of beehives during the winter and early spring has been conducted. Several different intensities of heat were employed, the heat being evenly distributed over a special crown-board, or applied to the colonies by means of a special heater frame upon which the bees could, and did, cluster. Nevertheless it was found, when the considerable body of data collected was examined, that the colonies to which heat was applied in no case wintered so well as the control colonies to which no heat was applied. Further, the " heated " colonies consumed considerably more stores of honey than the control colonies (13).

The drifting of drones from one colony to another (1) and the age groups of bees comprising a swarm (4) have been investigated by making use of large numbers of marked bees.

A series of comparative trials to determine the best methods

and times of feeding bees during the winter months, and the best concentrations of sugar syrup, etc. to use at these different times, have been carried out each year. The results appear to demonstrate that honey is better than syrup as a winter food for bees, but that a mixture of more or less equal proportions of honey and syrup is a satisfactory alternative: that the best results are obtained when the bees are left for winter with 35-40 lb. carbohydrate stores and some 4-5 British Standard brood combs full of pollen, and no winter or spring feeding is practised. So-called stimulative feeding in spring was found to be not only useless, but also wasteful of food unless the colonies of bees concerned were definitely short of either carbohydrate or protein stores, although not necessarily starving. If the bees were short of carbohydrate stores in spring, i.e., if each colony had not been left 35-40 lb. honey or honey and syrup, then the feeding of syrup was valuable, similarly if the bees were short of pollen stores, the feeding of soya-bean flour as a pollen supplement proved useful. It was not found that slow bottle feeding was at any time or in any way superior to feeding the same quantity of fluid in a rapid feeder.

Investigations on queen introduction, hive odour, etc. have been carried out during the period under review and have led on to a study of the problem of the "laying worker." The results obtained indicate that the "laying worker" which may be present much more frequently and in much larger numbers than the average beekeeper suspects, is often a most important factor in the successful introduction of queens to apparently normal colonies of bees. It has been found possible to produce "laying workers" in the laboratory and the problems of their origin and behaviour has, and is, being investigated.

Work on "colony balance," swarm control, bee breeding, etc. has also been carried out during the last few years, but these investigations are not yet sufficiently advanced for publication of the results obtained.

PUBLICATIONS

1. Butler, C. G. 1939. *The drifting of drones.* Bee World, **20**, 140-42.

Large numbers of drones belonging to several different colonies were marked with coloured paints, each colony being given its own distinguishing mark. Subsequent observation of the distribution of these drones in the apiary, which contained some 20 mating nuclei as well as 40 full-strength colonies of bees, led to the conclusion that drones seldom drift from their own hive into that belonging to another colony or even into a nucleus with a virgin queen. Drones will, however, join any swarms which happen to be about, being readily accepted and, having once joined them, remain attached to them thereafter.

2. Butler, C. G. 1939. *An automatic drinking fountain in the apiary.* Bee World, **22**, 119-120.

A well-protected, warm and easily cleaned drinking fountain with automatic control of the water supply by means of the float-chamber of a car buretter is described.

3. Butler, C. G. 1940. *The choice of drinking water by the honeybee.* J. Exp. Biol., **17**, 253-261.

The honeybee prefers dilute sodium chloride and ammonium chloride solutions to distilled water. She does not prefer concentrations of these salts higher than N/20 solutions, and solutions of various other salts to distilled water. The honeybee appears unable to distinguish between N/160 sodium chloride or N/160 ammonium chloride and distilled water. Bees are probably largely attracted to such sources of drinking water as rain water gutters choked with decaying organic matter, sewage effluent, etc., by a water perception sense coupled with an olfactory appreciation of various volatile substances contained in these sources of water.

4. BUTLER, C. G. 1940. *The ages of the bees in a swarm.* Bee World, **21**, 9-10.

As the result of marking experiments and the subsequent analysis of bees in eight prime swarms into age groups it is concluded that a swarm is largely composed not of the older bees, as had previously been assumed, but of the younger and middle-aged bees.

5. BUTLER, C. G. 1941. *A possible new cure for acarine disease of honeybees.* Nature, **148**, 86.

The vapour of terpineol, a heavy fraction of crude pine oil, was found to be highly toxic to the nymphs and adults of *Acarapis woodi* but to be harmless to adult bees and their brood.

6. BUTLER, C. G. 1941. *A study of the frequency with which honeybees visit red clover* (Trifolium pratense) *together with an examination of the environmental conditions.* Ann. Appl. Biol., **28**, 125-134.

Honeybees were found to work red clover, both first and second crops, for pollen and nectar. Two peak periods of activity, about 10.30 a.m. and 3 p.m. (G.M.T.) are exhibited by pollen gatherers; it is probable that these plants reach their peak of pollen dehiscence at these times. The visits of honeybees to collect nectar are chiefly determined by the height reached by the nectar in the corolla tubes of the flowers. When the sugar concentration of the nectar of red clover flowers was lower than that of other "honey" plants in bloom at the same time in the locality, or when the nectar was not sufficiently high in the corolla tubes for easy collection, bumblebees were usually more abundant on red clover than honeybees except at the peak periods of pollen collection. When conditions were suitable for the nectar collection five or six times as many honeybees as bumblebees were usually present. Few insects other than honey bees and bumblebees were found working red clover.

The honeybee carries on an average about 284,000 red clover pollen grains per load and visits a minimum of 284 flowers in collecting this load. In the U.S.A. honeybees have been credited with the cross-pollination of about 82 per cent. of the red clover crop, bumblebees with 15 per cent. and the hymenopterous, lepidopterous and dipterous pollinating insects with 3 per cent. No comparable data collected in this country are available for cross pollination of an important part of the seed crop.

7. BUTLER, C. G. 1943. *Bee paralysis, May sickness, etc.* Bee World, **24**, 3-7.

There are a number of complaints and one true disease of the honeybee which all exhibit very similar signs in the apiary, and which may conveniently be grouped together as Bee Paralysis. Nine types of Paralysis are distinguished, most of these being due to a dietary upset or poisoning. Paralysis due to the consumption of frost-damaged pollen, honeydew from lime trees, concentrated lime nectar, the spores of the fungi *Aspergillus calyptratus* and *A. versicolor*, etc., is described. It is pointed out that these forms of paralysis, although sometimes serious in their effects, soon disappear once the causative agent has been removed, which fact accounts for the sudden outset and equally sudden disappearance of the complaints in the apiary.

8. BUTLER, C. G. 1943. *The position of the honeybee in the national economy.* Ann. Appl. Biol., **30**, 189-191.

The main function of beekeeping in both peace and wartime is the provision of pollinators for fruit and seed crops. There is good evidence that in many places where large orchards or large areas of insect-pollinated seed crops are planted, there are insufficient wild pollinating insects present for full

production to be obtained. Man has upset the balance between the numbers of flowers requiring pollination and the number of pollinating insects available to effect their pollination. The honeybee is the only pollinating insect which can readily be used to redress the balance. It has been estimated that the average annual value of each colony of bees to the nation is about £12.

9. BUTLER, C. G. 1943. *Work on bee repellants. Management of colonies for pollination.* Ann. Appl. Biol., **30**, 195-196.

It was found that lime sulphur, nicotine and nicotine sulphate were all capable when added to spraying mixtures containing arsenic of repelling honeybees from collecting these mixtures as drinking water. If applied to open flowers, they had some, but not a 100 per cent., deterrent effect upon honeybees attempting to visit these blossoms.

10. BUTLER, C. G. *The incidence and distribution of some diseases of the adult honeybee.* Ann. Appl. Biol., **32**, 344-351.

Since 1918 four complaints of the adult honeybee, acarine disease, nosema disease, amoeba disease, and bee paralysis, have been recognised in this country. Surveys designed to discover the incidence and distribution of these diseases were carried out during the winters 1941-42 and 1943-44. It was found that none of these diseases is clearly confined to any definite areas of England and Wales. Acarine disease, however, is apparently more abundant in the west and south-west ; and nosema disease appears to be most prevalent in the home counties and also has other areas of heavy infection in Leicestershire and Cumberland, Lancashire and Yorkshire. Bee paralysis in its various forms is both widespread and common, and amoeba disease, although relatively rare, has been found to be widely distributed throughout the country.

11. BUTLER, C. G. 1945. *The behaviour of bees when foraging.* J. Roy. Soc. Arts **93**, 501-511.

From the 20th day of adult life onwards the young worker honeybee is concerned with the collection of water, pollen and nectar. She finds her way back to her hive from a foraging site by means of at least three senses, a sense of direction, a sense of distance travelled and also a sense which enables her to locate visual landmarks near her hive and to orientate herself correctly thereto. Bees do not wander at random over any given crop but confine their attention to a small area of the crop. These " fixation areas " of individual bees overlap to some extent and thus some cross-pollination is effected. It is nevertheless difficult to see at first sight how cross-pollination is effected in an orchard, as we know it is, where a single tree or even a part of a tree may serve as the " fixation area " of an individual bee. It has been found, however, that if the population of pollinating insects, and therefore the degree of competition, is sufficiently great, then there is a " wandering " population of bees seeking " fixation areas " of their own, superimposed upon the " fixed " population. It is this " wandering " population, which is mainly composed of young bees, which provides the cross-pollinators. It is now considered to be best for fruit growers to place colonies of bees maintained in their orchards for purposes of pollination together in one or more groups somewhere near the centre of each 30 acres of orchard, irrespective of the number of colonies available, rather than to scatter them about throughout the orchard. If this is done the grower can, over several years, find out the necessary number of colonies of bees of any given strength required if full production is to be obtained. Seed growers, whose problems are different, can none-the-less also use honeybees to advantage in many districts and also determine how many colonies of bees they will require.

12. BUTLER, C. G. 1945. *The influence of various physical and biological factors of the environment on honeybee activity. An examination of the relationship between activity and nectar concentration and abundance.* J. Exp. Biol., **21**, 5-12.

Both nectar abundance and concentration appear to have considerable effect upon honeybee activity. From the data at present available, it appears reasonable to conclude tentatively that nectar concentration decides in the first instance which species of plants will be visited in preference to others in flower at the same time, and that nectar abundance then determines the proportion of the foraging population of a colony which will work the flowers in question.

13. Butler, C. G. and Cockbill, G. F. 1942. *Preliminary investigations on the value of electric heating of beehives.* Ann. Appl. Biol., **29**, 34-42.

The general effect of all intensities of heating appeared in these experiments to be to reduce the area of brood present in mid April and to increase the winter consumption of stores, in direct contradiction to any belief in a beneficial effect on the colony.

14. Butler, C. G. and Finney, D. J. 1942. *The influence of various physical and biological factors of the environment on honeybee activity. An examination of the relationship between activity and solar radiation.* J. Exp. Biol., **18**, 206-212.

A review of the literature shows that those who have studied the influence of solar radiation on honeybee activity are agreed that it is an important limiting factor. Fresh analysis of some of this data, however, throws doubt upon some of the conclusions previously reached. New data were, therefore, collected which clearly show an association between variations in honeybee activity and the radiation of clear light.

15. Butler, C. G., Finney, D. J. and Schiele, P. 1943. *Experiments on the poisoning of honeybees by insecticidal and fungicidal sprays used in orchards.* Ann. Appl. Biol., **30**, 143-150.

Of the common constituents of spray mixtures only lead or calcium arsenate were found to be likely to cause serious honeybee poisoning, though Derris emulsion may cause slight poisoning. Lime sulphur, nicotine sulphate and copper sulphate are all repellent to bees. Concentrations of 1/500 lime sulphur or 1/2000 nicotine sulphate were sufficient to reduce the uptake of M/1 sucrose to less than 10 per cent. of that of unadulterated sucrose solutions. The presence of lead arsenate in these solutions appeared to make them even more repellent. Lead arsenate solutions were found to be no more attractive to bees than distilled water. Bees may collect arsenic when visiting fruit trees, or plants growing beneath or near the trees, for pollen and water, contaminated water apparently being the chief cause of poisoning. The addition of 1 per cent. lime sulphur was sufficiently deterrent to prevent bees collecting contaminated water. The other cause of arsenic poisoning is the collection by the bees of contaminated pollen and can be most serious. This form of poisoning can only be prevented by growers refraining from spraying open blossom.

16. Butler, C. G. Jeffree, E. P. and Kalmus, H. 1943. *The behaviour of a population of honeybees on an artificial and on a natural crop.* J. Exp Biol., **20**, 65-73.

In an experimental field filled with dishes of syrup to represent flowers individual bees were observed to visit one chosen dish with great regularity provided that the supply of syrup did not become exhausted. Bees were deterred from collecting syrup from dishes placed even partially in shade and they very seldom worked beneath the shade of trees. Over the range of distances covered (160-400 yards) there were always more visitors to the nearer than to the more distant dishes ; the extent of the difference, however, varied from day to day. Bees accustomed to collect syrup from the dishes furthest from the hive did not move to stations nearer home when the weather became unfavourable. There was some evidence, however, that bees working along way from the hive were more easily deterred from foraging by unfavourable weather than those working close to the apiary. Bees marked on a patch of *Epilobium augustifolium* situated in the midst of a fairly large crop of this plant, were usually recovered within 5 yards of the point of marking. Such bees remained " fixed " to this area for days. The same was found to be true with other plants.

17. Faberge, A. C. 1943. *Apparatus for recording the number of bees leaving and entering a hive.* J. Sci. Inst., **20**, 28-31.

An apparatus giving a continuous record of the number of honeybees leaving and entering a hive is described. Bees pass through a trap, producing electrical impulses. The recording part consists of a magnetic escapement causing a cursor carrying a type figure to travel above the paper. At regular time intervals the position of the cursor is printed, and it is brought back to the zero position. By actual test it was found that the escapement was capable of resolving a pair of impulses 1/100 second apart with certainty ; the resolution may be higher.

18. KRISHNAMURTI, B. 1939. *A brief analysis of eleven years* (1928-38) *records of scale-hives, at the Rothamsted Bee Laboratory.* Bee World, **20**, 121-123.

On the assumption that high temperature, long hours of sunshine and low rainfall are desirable for honey production, a rough classification of the weather conditions in the different years was made. This method, although only a rough one, immediately separated out the best years both for weather and honey production. It was found that years of favourable weather conditions appear to be succeeded by unfavourable ones more or less regularly.

19. MILNE, P. S. 1941. *Wax-moth and bald-headed brood.* Bee World, **23**, 13-14.

It was observed that larvae of *Achroia grisella* Fabr. are sometimes found lying alongside pupal honeybees contained in cells from which the normal cappings are missing. Masses of faecal pellets of the wax-moth larvae were found adhering to the pupae, many of which developed with deformed limbs. Burrows from cell to cell were observed. The large number of faecal pellets present and the absence of damage to the mid-rib of the comb suggests that the " Bald-headed " appearance is due to the cappings having been eaten away from below by the wax-moth larvae.

20. MILNE, P. S. 1943. *Brood diseases of the honeybee.* Ann. Appl. Biol., **30**, 191-194.

A discussion of the pathogenic organisms, etc., responsible for Chalk Brood, American Foul Brood, and European Foul Brood, and the methods by which these diseases are carried from one colony to another. The attempt to control the two Foul Brood diseases by mutual co-operation between bee-keepers and the aid of insurance schemes, and latterly by means of legislation, are described.

21. MILNE, P. S. 1943. *The spread of American foul brood.* Brit. Bee J., **71**, 298-300.

A discussion, with a diagrammatic representation of eleven ways in which *Bacillus larvae* becomes distributed within a hive of bees, and of ten ways by means of which the disease spreads from one colony of bees to another.

22. MILNE, P. S. 1945. *Brood diseases in the three counties.* Wilts, Hants and Dorset Beekeepers' Federation 1945 Year Book, 6-11.

During 1944, 706 apiaries of bees in Wilts, Hants and Dorset were visited by officers appointed under the Foul Brood Disease of Bees Order, and 2,253 colonies of bees in these apiaries were examined. Foul Brood was found to be present in approximately 1 in 4 of the apiaries visited, and in 1 in 8 of the colonies examined. For England and Wales as a whole the corresponding figures are 1 in 6 and 1 in 14 respectively, based on reports from 52 counties and on inspection of 23,000 colonies of bees in 6,000 apiaries.

23. MILNE, P. S. 1945. *Sulphonamides and American foul brood disease of bees.* Nature, **155**, 335.

In 1944, Prof. Haseman of the University of Missouri, Columbia, reported that sugar syrup containing sulphathiazole fed to bees enabled them to raise healthy brood in combs containing the " scales " of larvae which had died of American Foul Brood. In 1943 a beekeeper, Mr. Ekins of Surrey, claimed to have obtained similar results with sulphapyridine. Trials, with sulphapyridine for the eliminaton of A.F.B. from colonies of bees, carried out at Rothamsted in 1944, yielded promising but not conclusive results. It appeared that during the course of treatment, progress of the disease within the colony was arrested, and that only healthy brood was being reared in combs where the disease had previously been established.

Other Publications :

24. BUTLER, C. G. 1945. *Beekeeping.* Bull. No. 9. Ministry of Agriculture and Fisheries.

25. BUTLER, C. G. 1945. *Advice to intending beekeepers.* Leaflet 283. Ministry of Agriculture and Fisheries.

26. BUTLER, C. G. and MILNE, P. S. 1945. *Diseases of bees.* Bull. No. 100. Ministry of Agriculture and Fisheries.

27. MILNE, P. S. 1944. *Foul brood.* Leaflet 306. Ministry of Agriculture and Fisheries.

DEPARTMENT OF INSECTICIDES AND FUNGICIDES

By F. Tattersfield

During the war period there were considerable changes both in personnel and type of work in this department. Drs. J. T. Martin and S. H. Harper, who for a number of years had been engaged on detailed studies of plant insecticides such as pyrethrum (*Chrysanthemum cinerariifolium*) and derris, left (1942) to take up other appointments.

During the three years (1939-42) Dr. Martin undertook a considerable amount of urgent work, particularly upon the dermatitis factor in pyrethrum and, with Dr. Brightwell of the Imperial Institute, of the chemical evaluation of pyrethrum-in-oil sprays, which is likely to be permanently valuable. Dr. Harper continued his important researches on the constitution of the active principles of derris and other plant insecticides.

New appointments have been Messrs. K. A. Lord (1942), A. H. McIntosh (1944) (chemists), Mr. M. J. Way (entomologist) (1943), Mrs. E. M. Gillham (1942 and Miss R. I. Stoker (1943) (horticulturists). Mr Lord has been chiefly engaged in researches on the following subjects; (*a*) the preparation of dermatitis-free pyrethrum extracts; (*b*) the revaluation of the factor for determining Pyrethrum I; (*c*) the synthesis and insecticidal valuation of D.D.T. analogues; (*d*) the stability of D.D.T.; (*e*) with Mrs. Dion of the Plant Pathology Department on the fungistatic properties of the triphenylmethane dye-stuffs. Mr. McIntosh has worked on a micro-method for determining D.D.T., and the effect of particle size and shape on its insecticidal value. Dr. C. Potter has been in general oversight of the entomological side of the Department's work and with Dr. Tattersfield has investigated what was in the early days of the war the urgent problem of the biological evaluation of pyrethrum-oil preparations. With Mrs. Gillham he has studied the effects of environmental conditions on the susceptibility of insects to a number of insecticides including D.D.T., and had, with Mr. Perkins of the Plant Pathological Department of the Ministry of Agriculture, general charge of the field experiments with D.D.T. Mr. Way, in addition to the investigation of methods for determining the insecticidal potency of stomach poisons, has carried out with Miss Stoker investigations of the effect of leaf growth upon the insecticidal value of D.D.T. and the effect of D.D.T. upon parasites and predators. Mrs. Gillham and Miss Stoker have provided the extensive stocks of plants needed to rear the very large number of insects required and have carried out investigations on the phytocidal action of D.D.T., in addition to helping in the spraying trials and assessing the results. Throughout this period, therefore, the work of the Department has been concerned with

(*a*) laboratory techniques for evaluating insecticides,
(*b*) insecticides of plant origin,
(*c*) the new synthetic insecticide known as D.D.T. (2, 2-bis-parachlorophenyl 1, 1, 1-trichloroethane).

At different periods of the war such insecticides as pyrethrum, derris and D.D.T. were withdrawn from agricultural and horticultural use to other more urgent purposes and could only be obtained in experimental quantities. A good deal of the work carried out was not published, but incorporated in confidential reports. It was considered important that before D.D.T. was released in large-scale amounts for general purposes more should be learnt of its possible uses and dangers in the horticultural and agricultural field. Part of this work has been undertaken here at the instance of a sub-committee of the Agricultural Research Council.

This review, presented in yearly periods, is in general divided into three main categories; (*a*) biological, (*b*) biological-chemical, (*c*) chemical investigations, but all three are closely interlocked.

PERIOD 1938-39

Biological investigations. (*a*) *Insect rearing*

During this period and, in fact, during the whole period under review a considerable degree of attention was devoted to the study of the facilities and the techniques needed for rearing insects under controlled conditions and the selection of such insects as were suitable for testing insecticides. A constant-temperature-and-humidity room together with an incubator was set up and found to be suitable for rearing a number of stored-products pests, which being readily available throughout the year have often tided us over periods when plant feeders were not available. In addition, *Macrosiphoniella sanborni* (chrysanthemum aphis) was investigated and found to be available for many months of the year. It is a useful insect for the preliminary testing of new insecticides, as it is one of the more susceptible species. *Plutella maculipennis*, the caterpillar of which was suitable for stomach-poison trials, was closely investigated: it is readily reared at all periods of the year, and has proved a great stand-by in working out a laboratory technique for the quantitative assessment of the toxicity of this class of insecticide.

(*b*) *Contact insecticides.* During this period the elaboration of the larger spray tower was completed (14). It is a development of the Tattersfield-Morris spraying apparatus, but more suitable for quick-moving insects, as an even distribution of spray over a greater area with control of doses is secured, but difficulties of replication are being met with. We have available now two machines—the original Tattersfield-Morris apparatus, for which only small amounts of insecticide materials are required, and the larger Potter apparatus for normal use.

Biological-chemical investigations

(*a*) A prolonged study (9) was undertaken of the relative toxicities of the fractions of derris resin to *Aphis fabae.* Rotenone was thus compared with the so called deguelin concentrate (neutral resin not extracted by alkali) and with the sumatrol-toxicarol fraction (extracted by alkali), and the toxicities of these expressed in terms of their rotenone equivalent. Thus the deguelin concentrate was $\frac{1}{4}$—$\frac{1}{6}$ and the sumatrol-toxicarol complex $\frac{1}{12}$—$\frac{1}{15}$ as toxic as rotenone. Rotenone and these fractions could be determined

chemically. Thus from the chemical analysis of four samples of derris root of different varieties it was predicted that the relative toxicities would be 1, 1·3, 1·7, 2·7. The biological determination of the toxicities gave 1, 1·5, 1·7, 2·6. In addition, the toxicities of the available pure active principles were determined. Elliptone was foung to have a potency of one-third to one-fifth that of rotenone, toxicarol and sumatrol being less toxic.

(*b*) Preliminary investigations of the effect of media on the toxicity of insecticides were made. It was found that *Calandra* (*Sitophilus*) *granaria*, the grain weevil, was highly resistant to derris resin when applied in an acetone sulphonated lorol medium, but incorporated in a heavy oil sulphonated lorol emulsion, derris extract was an effective insecticide. Heavy oils at the same concentration and deposit were non-toxic, but were so at higher deposits. The wetter used had a pronounced importance, as was shown by the greater toxicity of derris extracts applied in alcohol sulphonated lorol over the same extract in 10 per cent. alcohol saponin medium.

Other insecticidal plants (8). An Indian sample of *Munisuka sericea* (Supli) was found not so toxic to insects as the rotenone-rich species of derris roots now obtainable, but it was of interest as it was found that the leaves, bark and roots all possessed insecticidal properties, whereas in the African strain of this plant the bark is the only toxic part. Cashew-nut shell oil was found to possess some toxicity. The chief investigation, however, concerned four species of *Annona* received through the Colonial Office from Ceylon. They all proved aphiscidal in varying degrees, but *Annona reticulata* seed, leaf, stem and root, particularly the seed and root, had a considerable measure of toxicity of a delayed-action type to both the chrysanthemum and bean aphis. The action is specific to certain species, some insects being unaffected when extracts are administered by contact or as a stomach poison.

Chemical Investigations. The determination of rotenone (17)

This was a conjoint piece of work with the Imperial Institute the Department of Agriculture of the Federated Malay States and the Cooper Technical Bureau. Completely concordant results were not obtained by two methods even when details of procedure were minutely defined. A modified technique was detailed for study upon another batch of samples of specified varieties.

The active principles of derris. A new derivative, which has been named elliptone, closely related to rotenone, was isolated by Dr. Harper (6(*a*), 6(*b*), 7) : it has an *iso*-rotenone structure, but is devoid of the propyl side-chain. This structure was confirmed by degradation experiments. Elliptone also differs from rotenone in not forming a carbon-tetrachloride complex. The hydroxyl derivative, previously found by two Dutch workers, was also isolated and was found to bear the same relationship to elliptone as sumatrol does to rotenone (10).

A sample of "White-milk" Haiari, a species of Lonchcarpus from British Guiana, was found to contain 2·3 per cent. of rotenone, which was also shown to be present to the extent of 0·5 per cent. in *Tephrosia toxicaria*.

PERIOD 1939-40

Biological investigations

These were a continuation of those of the previous year, but no new insect test-subject superior to those already in use was discovered. Much time and attention were given to the problem of obtaining in large numbers the eggs of *Ephestia kühniella* (Medi-, terranean flour moth), *Sitotroga cerealella* (Angoumis grain moth) and *Pieris brassicae* (cabbage white butterfly), needed for investigations to be detailed later. A commencement was made in the long-term study of the relative susceptibilities of insects to insecticides.

The difficulties met with in replicating the amounts of deposit obtained in the Potter spraying tower were overcome after prolonged effort. Evenness of distribution and facility of repeating the amounts of deposit appear to be mutually exclusive. The reason is that the apparatus depends for its effectiveness upon the spray being thrown into a state of turbulence in the upper part of the spray tower used. A turbulent stream is largely out of control and susceptible to abrupt variation in character with minute changes in environment. A careful analysis was made of the factors involved —e.g. the turbulence, its subsequent subjection to streamlining as induced by the shape of the tower, and the effect of the size of the vents at its top and bottom upon both. A study was made of the pressure and regularity of flow of air to the nozzle, the latter's structure, and the electrification of the droplets of spray as they issue from the nozzle. Finally, there was evolved the present apparatus—an earthed, metal tower of circular section, open at the top except for a centrally placed, adjustable, atomising nozzle and reservoir. The tower tapers to the centre and then becomes cylindrical. A platform upon which the insects are placed, can be rapidly moved into position, leaving an accurately spaced gap between it and the bottom of the tower. A good distribution with good replication was thus obtained, and the whole apparatus and technique are flexible enough to allow of wide variation in deposit of the insecticide sprayed and of considerable speed in operation (14).

Biological-chemical investigation

These followed up the work carried out in 1938-9. (*a*) The extracts derived from the seed of *Annona reticulata* were fractionated and tested biologically. One of the fractions was found to have an insecticidal value of the same order as some of the derris extractives. (*b*) Trials were made to determine the most suitable solvent for extracting pyrethrum for analytical purposes. The value of petroleum ether for this purpose was confirmed (15). (*c*) The toxicity values and rotenone equivalents of various crystalline derivatives from derris were re-determined (16). (*d*) The effect of media and adjuvants upon the toxic action of constituents of derris was determined. Phenol accentuated, cyclohexylamine depressed, the insecticidal value of rotenone. Terpineol increased the toxicity of this compound to *Oryzaephilus surinamensis*. (*e*) Advantage was taken of a considerable invasion of cabbage-white butterflies to test in a preliminary way the effect upon their eggs of a variety of plant insecticides. Rotenone and pyrethrum extracts were each found to have a powerful ovicidal action (25).

Dermatitis factor in pyrethrum (13). Being susceptible to the dermatitis effects of pyrethrum, and this insecticide being of considerable importance for the control of insect pests during the war, Dr. J. T. Martin volunteered to undertake with Dr. K. H. C. Hester, a local medical man with experience of dermatitis problems, an investigation of the causal factors of this painful complaint affecting certain susceptible people who handle or are exposed to pyrethrum flowers, sprays and dusts. Much valuable information was obtained and a report submitted to the Medical Research Council, who suggested a medium for publication. In the course of the work Dr. Martin prepared a concentrate containing 93 per cent. of pyrethrins that had only a very slight irritant effect, thus the active principles are not responsible for dermatitis. On the other hand a constituent, volatile in steam, gave a most powerful and painful reaction, although other preparations and fractions in varying degrees gave rise to characteristic skin effects. The work, it was hoped, might lead to the preparation of dermatitis-free extracts.

Chemical investigations

(*a*) *Determination of rotenone* (17, 22). The co-operative work was continued. A committee, composed of a group of investigators in this country, suggested a new method of analysis and six samples of derris root of different types, but of known origin, were analysed by the participating laboratories. The results showed a good agreement among the workers in this country, but the figures obtained by chemists in Malaya were of a lower order, probably because of climatic conditions.

(*b*) *The active principles of derris.* The constitution of the new phenol compound (malaccol) was established. Five out of the six derivatives of derris have now been isolated in an optically active state. Deguelin has eluded separation so far, and has only been obtained in a racemic form. A compound from *D. malaccensis* with insecticidal properties that seems to be new was isolated, but the amount obtained was too minute for critical work. Studies of *l*-a-toxicarol, first isolated by Tattersfield and Martin, showed that its anomolously high methoxyl content was due to the presence in minute amounts of a derivative with a high methoxyl content. Dr. Harper (11, 21) suggested that it may have a flavone or *iso*-flavone structure and be the precursor of one or other of the rotenone-like compounds isolated. The determination of its structure would need the separation of much larger amounts than have been, so far, available.

(*c*) *Annona species.* The fractionation of the extractives has shown that the fraction soluble in ethyl ether *but not in petroleum ether* has a high toxicity to aphides. It is of the same order as that of some derris extractives.

PERIOD 1940-41 : 1941-42

During this period pyrethrum insecticides assumed a major role owing to their use for the rapid control of many pests of importance to the war effort and to public health. Their use in warehouse sprays for controlling pests of stored food, in air-raid

shelters and on men for the control of pests of medical interest made pyrethrum a subject of some importance to the Ministry of Food, the War Office and the Medical Research Council. Finally all supplies were taken over by the Government and use restricted for certain limited purposes. During this period, however, we were consulted on pyrethrum preparations by a number of interested bodies, such as the Entomology Department of the School of Hygiene, Dr. Page of the Ministry of Food on certain aspects of their use, and for a short time Dr. J. T. Martin co-operated with Dr. Mellanby in his experiments on scabies control. We were requested by the Agricultural Research Council to take up certain pyrethrum investigations as matters of urgency.

The investigations undertaken and continued in this period were ;—

(*a*) *Chemical analysis of pyrethrum-in-oil preparations.* In conjunction with the Imperial Institute a suitable method has been worked out for determining pyrethrin I in these preparations. The method was shown to give accurate results with two types of commercial preparations used for warehouse and air-raid shelter spraying. The method was the subject of a report to the authorities concerned and has since been extensively used.

(*b*) *Biological testing of pyrethrum-in-oil preparations* (23). One of the commonly used methods of applying pyrethrum is in the form of an oil spray. Our work involved the study of two techniques of evaluation in which the insect was subject (i) to direct spray, (ii) to the effect of a film formed after spraying. In addition, the methods of preparing standard solutions of pyrethrum-in-oil for purposes of comparison had to be undertaken.

It was found that provided the insect test-subject, in this case *Tribolium castaneum*, were of good quality, free from parasites and disease, and reared and handled in a uniform way, both methods (i) and (ii) were satisfactory for quantitative insecticide tests, but the factor of insect quality was most important if reliable results were to be obtained. The Potter spraying apparatus, after a little adaptation to meet the special case of pyrethrum-in-oil sprays, was found suitable for the application of the two methods. A special cupboard ventilated by fan and incorporating electric warming equipment was built to house it.

For both techniques (i) direct spray and (ii) film, the surface upon which the spray falls or the oil film is formed very largely determines the degree of toxicity : the less absorptive the surface the higher the kill and the steeper the characteristic toxic curve. In addition, the weight of the deposit per unit weight of fluid sprayed is altered by slight changes in the physical properties (e.g., viscosity) of the pyrethrum preparations. Moreover, the period of time the insects are left on the film determines its toxic effect. These difficulties were overcome by using surfaces of constant sorptive properties, (e.g. tricoline or hardened filter paper, Whatman No. 544), by determining the weights of deposits per unit area at frequent intervals, and by keeping the insect on the film for a constant period (five days).

For comparing the two techniques (i) direct spray and (ii) film, the concentrations in terms of pyrethrins and the deposits

per unit area were successively changed and the toxic effects noted. The results plotted as probits against the log concentrations and log deposits were analysed by D. J. Finney who introduced a new statistical concept—that of probit planes for purposes of analysing toxicity data involving the three variables. It was found that the planes were parallel, that the direct-spray technique gave the higher kill, and that so far as homogeneity of data was concerned there was no significant difference between the direct-spray and the film techniques.

(iii) Standard pyrethrum-in-oil preparations of known and repeatable constitution were prepared (24), requiring a considerable amount of work on processes of extraction and blending. Three such preparations were prepared, and their insecticidal values were compared with each other and with commercial preparations.

The application of the direct spray technique showed that a 10 per cent. difference in pyrethrin content could be readily detected, that is, a composition containing 1·0 per cent. of pyrethrins could be differentiated from one of 0·9 per cent. When the film technique was applied to commercial preparations the presence of sludge or slime could introduce heterogeneity into the data. The sludge could probably be safely separated out since its presence had no very marked effect on the toxicity of the pyrethrins. Apparently no constituent of the commercial preparations tested, other than the pyrethrins, had any effect upon toxicity. With oil sprays relative potency was more closely correlated with *total* pyrethrin content than with pyrethrin I, a finding which led to an investigation of the effect of media on the toxicity of the pyrethrins. It was found that pyrethrin I was more toxic than II in aqueous media, but they were of the same order of potency in petroleum oil.

The loss of activity of pyrethrum. Its quantitative determination (23)

Pyrethrum extracts are highly repellent to mosquitoes. At this time considerable attention was being given to the preparation of ointments for this purpose, and the problem of their possible loss of activity at tropical temperatures was referred to us through the Agricultural Research Council, by the School of Hygiene and Tropical Medicine. Two types of ointment were sent in to us, embodying pyrethrum extracts with (i) gum tragacanth and (ii) soft wax. The preparations were exposed to the temperatures of (i) refrigerator (taken as control), (ii) 35° C., (iii) 50-60° C. The tests were thus very drastic. The loss of toxicity was determined by both chemical and biological means. The results agreed within close limits. A gum-tragacanth preparation in 14 days at 50° C. showed a loss of pyrethrin I and II *determined chemically* of 11·8 per cent. w/w. The loss of activity *determined biologically* was 12·8 per cent. The soft-wax preparation kept at 50° C. for 14 days showed loss of pyrethrin I and II *determined chemically* of 12·5 per cent. w/w. The loss of activity, *determined biologically* was 16·5 per cent. (in the latter case the temperature rose for some days above 50° C.). The loss at 35°C. is not significant.

Insecticides applied jointly, the effect of adjuvants and media

These investigations were carried a stage further, but owing to other more immediately important problems, they were somewhat

intermittently pursued. The work upon the toxicity of the active principles of derris applied alone and together was completed. Using a statistical technique developed and published by Mr. Finney of the Statistical Department, Dr. J. T. Martin (16) showed that the constituents of derris had no synergistic effect on each other's toxicity and that therefore his earlier work upon the assessment of the toxic value of derris root by the determination of its rotenone equivalent is not invalidated by this cause.

Ovicidal action of plant insecticides

This investigation was nearly completed. It was shown that both derris and pyrethrum have ovicidal effects in certain cases and at certain stages of egg development, but that derris extract is not toxic to red-spider eggs.

Derris. Dehydro-tetrahydroelliptone was synthesised, confirming the formula ascribed to elliptone from degradative experiments (20). Toxicity experiments showed that *l*-elliptone was more toxic than *dl*-elliptone, and *l*-dihydroelliptone than *dl*-dihydroelliptone, a conclusion confirming that among this class of compounds the optically active (*laevo*) compounds are quantitatively more powerful insecticides than the racemic compounds (19). The results confirmed earlier more detailed and exact results that rotenone was five times as toxic to *Macrosiphoniella sanborni* than elliptone. The contaminant of *l-a*-toxicarol having been shown to be an *iso*-flavone, a series of analogous compounds was prepared which were remarkable in giving the Durham test characteristic of rotenone, but they had no material insecticidal potency.

Annona species. Further work demonstrated that both the seed oil and the root contained insecticidal principles with very similar properties. The action was slow, but the order of toxicity was high, and to certain aphides was comparable with that of rotenone. The fractionation of the seed oil gave a toxic portion which a preliminary examination showed to be a glyceride of a hydroxylated acid of unusually high molecular weight. The slow but cumulative paralytic action on insects is of interest. An investigation of *Pongamia glabra* from India proved the insecticidal properties to be concentrated in the flavone fraction of the extracts of the seed. Cashew-nut shell oil was examined and cardanol (its active principle) shown to be ovicidal. The cardanol distillate was separable into an easily reducible and a non-reducible portion.

Biological work

Work continued on the rearing of plant-feeding test insects. Those so far reared have proved very useful, but the search for others continued with the result that the aphis, *Macrosiphum solanifolii* was kept going throughout the year. For successful rearing, it requires a succession of host plants. It has been a promising test-subject and a welcome discovery, since the aphis *Macrosiphoniella sanborni* during the year fluctuated both in quantity and quality.

Relative susceptibility of insects to insecticides

Effect of external conditions. The problem of the effect of environmental factors upon insect resistance was examined and the tem-

perature at which the insect was kept after spraying was found to have a pronounced effect on the subsequent mortality induced by pyrethrum sprays—recovery being helped by higher temperatures.

General susceptibility. Preliminary exploratory work was started upon the relative toxicities of the pyrethrins, rotenone and derris resin, and lauryl thiocyanate to a number of insects under approximately similar conditions with the object of ascertaining :—

(i) How far the results obtained with a given insecticide on one insect are applicable to other species.

(ii) To what extent the order of toxicity of a series of insecticides will vary with the insect test-subject.

Although a number of experiments were carried out, this long-term research had to remain in partial abeyance owing to pressure of other work.

PERIOD 1942-43

During this period large changes in the future programme of work had to be arranged. Funds were made available for the employment of two new assistants, and an entomologist (M. J. Way) and a horticulturalist (Miss E. M. Mills, later Mrs. Gillham) were appointed. The proposals are of a long-term character and have meant a careful review of our programme of work, which during the year was discussed with and approved by Messrs. Fryer and Gimingham of the Ministry of Agriculture. Although the main outline was drawn, much interruption in carrying it out supervened. Drs. Martin and Harper left in 1942, and although Mr. Lord was appointed in August 1942, and he rapidly familiarised himself with many of the details of the several lines of investigation and has done valuable work, there was inevitably a slowing-down in the carrying out of our programme.

Chemical investigations were chiefly concerned with pyrethrum. The possibilities of separation of the pyrethrins I and II by means of preferential sorption of the chromatographic type were explored in a preliminary way by Mr. Lord, and progress was made. The method of pyrethrin determination in pyrethrum-in-oil preparations, which had been worked out conjointly by this Station and the Imperial Institute, was found to give erroneous results for very dilute solutions. A satisfactory solution of the difficulty was found by increasing the time of reaction, the concentration or volume of sodium hydroxide in the saponification process.

Fungicidal properties of synthetic dyes

Mr. Lord (in collaboration with Mrs. W. M. Dion of the Plant Pathology Department) (26) compared the toxicity of salts and bases of a number of dyestuffs to spores of *Fusarium culmorum* and *Cercosporella herpotrichoides*. Mr. Lord prepared a certain number of the salts and bases. The findings were as follows. (*a*) The basic dyestuffs of the triphenylmethane series were highly toxic and/or highly fungistatic, irrespective of the acid radicle associated with the dye. (*b*) Malachite Green base (tetramethyl-p-diaminotriphenylcarbinol) showed high toxicity which was, if anything, progressively lowered by substituting the methyl groups

by ethyl, propyl, and butyl radicles. (*c*) The *leuco* bases were not toxic. (*d*) In triphenylmethane compounds the substitution in the benzene nucleus of acid groups lowers toxicity, of basic groups increases activity. Sulphonation or carboxylation of any of the nuclei lowers toxicity to the vanishing point. (*e*) The introduction of aniline or dimethylaniline radicles into the methane radicle progressively increases toxicity. (*f*) Naphthylamine and diphenylamine radicles can partially replace dimethylaniline radicles without loss of activity. (*g*) Bridging between benzene nuclei by oxygen or nitrogen tends only to slight increases in toxicity. (*h*) The central carbon atom can be replaced by nitrogen, the diphenyl-ammonium compounds were, however, somewhat less active than the triphenylmethane dyes. (*i*) Some dyestuffs, e.g., Eriogreen S.F.L., Erichrome Azural and Erichrome Cyanine, and Tetraethyl-p-amino-p-sulphonate stimulated the growth of the hyphae of *Fusarium culmorum* and hastened sporulation, an observation which has aroused interest.

Biological work

The means of providing a range of insects suitable for use as test-subjects were further and more extensively studied. The object is one of importance since the range has to be wide enough to enable us to ascertain the degree of specificity of an insecticide, if any. Moreover, as many species as possible should be available throughout the year. Insects successfully reared were *Macrosiphoniella sanborni*, *Aphis* (Doralis) *fabae*, *Macrosiphum solanifolii*, *Macrosiphum pisi* amongst the aphides; *Plutella maculipennis*, *Euxoa segetum*, *Tortrix pronubana*, *Orgyia antiqua* among the lepidopterous insects: and *Otiorrhynchus sulcatus*, *Ceutorrhynchus quadrimaculatus* and *Phaedon cochleariae* among the coleoptera. Such insects were devoted to a number of investigations, among them the following:

1. The elaboration of apparatus and technique for the study and evaluation of insect poisons. Thus the apparatus for testing contact poisons was extensively used for examining new insecticides against insects and their eggs. But where it was inapplicable—as for example with red-spider eggs—a dipping technique was evolved and used. An investigation of methods for testing stomach poisons was commenced—a seriously felt want, but difficult to meet—and considerable progress was made during the year.

2. *Work on the environmental factors affecting the susceptibility of insects to various insecticides.* The effect of the host plant and the physical conditions ruling *before*, *during* and *after* spraying were examined as well as the relative susceptibility of a number of species to different insecticides. It was clear that certain elaborate apparatus and equipment would be needed for the adequate prosecution of these researches, including constant temperature and humidity chambers and rooms with facilities for rearing, spraying and storing insects and their plant hosts under controlled conditions.

3. *Ovicidal Tests.* Red-spider eggs on apple twigs and the dipping technique with temperature accurately controlled were used. The twigs were dipped for a definite time in thermostatically controlled reservoirs containing the insecticide at appropriate concentrations. When dry the eggs in marked-out areas were immediately counted, and again some months later. Thus the unhatched eggs were deter-

mined. 3 : 5 dinitro-*o*-cresol was toxic to the eggs both in benzene and heavy petroleum oil, but the most interesting effect observed was that the susceptibility of the eggs was greater in May than February: pyrethrum, for example, not normally regarded as ovicidal, had little effect at the earlier, but was definitely toxic at the later, date.

4. *Indigeneous Plants.* A number of these received from the Royal Botanic Gardens, Kew, occupied a good deal of our attention. A few with suggestive names like Flea-bane showed some slight effect as contact insecticides to aphides—but only one, *Euonymus europaeus*, the Spindle or Louseberry was worth extended investigation. The fruits of this plant had some toxicity, but were not anything like as toxic as pyrethrum flowers, readily grown, but not indigeneous to this country.

5. *Ad hoc* investigations were referred to the department, among which the most important was a preliminary survey of the insecticidal potentialities of D.D.T. to horticultural and agricultural insect pests. A report was sent to the Ministry of Agriculture and the Agricultural Research Council.

This department had very early contacts with D.D.T. and had directed the attention of the appropriate authority to its reputation in Switzerland for louse control. On this side its use was developed by Professor Buxton and others to such good purpose that all but experimental supplies were appropriated for war service. Beyond reports sent out by Messrs. Geigy of Basle, little was known of its range of usefulness in agricultural and horticultural fields. This investigation was now undertaken. D.D.T. was, therefore, tested in the laboratory on the following natural orders; Lepidoptera (larvae, five), Hymenoptera (fully grown larvae, two), Coleoptera (adults, two), Rhyncota (apterous viviparous females, five species).

It was clear that to the larvae of the Lepidoptera such as the cabbage-white butterfly, diamond-back moth, tortoiseshell, vapourer moth, D.D.T. was a powerful insecticide. It was less effective against the lesser wax moth and to this insect its toxic action was of a very slow and delayed type. Larvae of such Hymenopterous insects as Solomon-seal sawfly, (*Phymatocera aterrima*) and the social-willow sawfly (*Pteronides pavida*) were susceptible. D.D.T. was much more toxic than nicotine to the first and comparable with the pyrethrins to the second. To the Coleoptera *Tribolium castaneum* and *Oryzaephilus surinamensis*, both stored-products pests, D.D.T. had a high potency. Applied in heavy oils to the adults of *T. castaneum* it proved effective.

To *Thrips tabaci* on vegetable marrow, applied at 0·1 per cent. w/v, D.D.T. was effective as a control measure but there was some indication of foliage damage.

In the case of the natural order Rhyncota, apterous viviparous females of the aphides *Macrosiphoniella sanborni*, *Macrosiphum urticae*, *Macrosiphum pisi*, *M. solanifolii* and the winged nymphs of *Pterochlorus saligna* were used. D.D.T. did not prove as toxic as was expected from analogy with its powerful effects upon the body louse and some other insect pests. Some difficulty was met in preventing the aggregation of crystal particles when solutions of D.D.T. in water-soluble organic solvents were added to water

containing a wetter and spreader, and although some improvement was obtained when a proprietary dispersing agent of the firm of Messrs. Geigy was used, further difficulty was met in comparative trials in that this product seemed if anything to antagonise the toxic action of the pyrethrins and rotenone: the latter were, therefore, dispersed in an acetone-sulphonated lorol water medium. Quantitative experiments showed D.D.T. to be of the same order of toxicity as nicotine to *M. pisi*, *M. urticae*, *M. solanifolii* and less toxic to *P. saligna*. Using the last named insect as a test-subject it was not in the same category as a contact insecticide with either rotenone or the pyrethrins. The delayed action of D.D.T.—it requires two to three days for its full effect upon certain aphides to be shown—was a complicating factor, since extensive reproduction proceeds even with partially paralysed insects; thus it is probable that in the field it might prove even less successful against such resistant species as *M. solanifolii* (potato aphis), *P. saligna* (willow aphis) and *Aphis fabae* (bean aphis).

Dermatitis factor in pyrethrum. Since Martin and Hester had shown (p. 210) that the pyrethrins were not the causative factors of the serious dermatitis effects in susceptible people, attempts were made to free pyrethrum extracts of the serious effects. Mr. Lord carried out as a matter of urgency a number of extraction experiments with some degree of success. Trials made at the School of Hygiene and by the R.A.M.C., at Aldershot showed that his preparations were much less irritant than normal ones. The work was not proceeded with as D.D.T. began to replace pyrethrum for certain work and synthetic organic compounds took its place as a mosquito repellent.

Period 1943-44

Early in 1944 a sub-committee of an Insecticides Conference, called by the Agricultural Research Council, asked us to undertake together with Long Ashton and East Malling Research Stations both laboratory and field work on the possibilities of D.D.T. for controlling horticultural and market-garden pests, particularly the latter. A great deal of the time of the laboratory was consumed on it. The work we were able to do can be divided under three headings;—

(*a*) Laboratory tests for the determination of the relative toxicities of D.D.T. in different media.
(*b*) Laboratory tests to compare the toxicities of D.D.T. and other insecticides to a number of species of insects.
(*c*) Trials to ascertain the persistence of D.D.T. under weathering.
(*d*) Field trials to ascertain the value of D.D.T. as a control measure for certain pests affecting farm and market-garden crops.

(*a*) *Laboratory tests on the effect of media on the toxicity of D.D.T.*

This work arose from the fact that in 1943 D.D.T. was found not to have any outstanding toxic action to aphides and it was suggested that the effect of the medium might be a deciding factor. Dr. H. Martin of Long Ashton Reasearch Station prepared two concentrates of D.D.T. using different media, (*a*) in which it was dissolved in acetone carbitol and dispersed as suspensoid on dilution with water containing sulphonated lorol T.A. as a wetter, (*b*) in

which a benzene solution containing also an organic emulsifier (cyclohexylamine dodecyl sulphate) was dispersed as an emulsion when diluted with water.

Crystal-aggregation difficulties were met with in the higher concentrations of (*a*), but these were partially overcome by speedy operation of the spraying technique. The slowness of toxic action, however, was not surmounted and this necessitated a careful selection of test-subjects sufficiently hardy not to be affected by the basal media and of a sufficiently long natural life-period to permit of the determination of the toxic action of the slow-acting chemical compound. The results obtained indicated that D.D.T. was a more effective insecticide to the aphid *Macrosiphum solanifolii* when applied as an emulsified solution in a water-insoluble organic liquid (benzene) than as a suspensoid set free from a water-soluble organic liquid.

(*b*) *Comparative laboratory trials with D.D.T., nicotine, rotenone and pyrethrins to a number of insects*

Comparisons as contact insecticides made at L.D. 50* gave the following results as relative toxicities;

	Nicotine	Rotenone	Pyrethrins	D.D.T.
Myzus cerasi (Cherry aphis) ..	1	48	—	1
Phaedon cochleariae (Mustard beetle adult)	1	102	—	16·4
Pieris brassicae (cabbage-white butterfly larvae)	1	—	25-26	6·2
Phymatocera aterrima (Solomon-seal sawfly larvae)	1	500-1,000 (approx.)	500-1,000 (approx.)	20-40 (approx.)
Pteronus ribesii (Gooseberry sawfly larvae)	1	450	—	11
Cheimatobia brumata (Winter moth larvae)	1	—	—	114

The larvae of the small ermine moth were relatively highly resistant to both D.D.T. and nicotine. To the bean aphis D.D.T. was somewhat less toxic than nicotine.

Comparative trials were carried out with both lead arsenate and D.D.T. as stomach poisons to the larvae of *Plutella maculipennis*. It was found that at the median lethal dose D.D.T. was approximately ten times as toxic as lead arsenate.

Tested as a spray on Plutella eggs it was found that at a concentration of 0·25 per cent. there was a definite toxic action and although the larvae developed normally in the egg, only 47·66 per cent. emerged successfully.

(*c*) *The persistence of D.D.T. under weathering*

Three series of tests were undertaken in which cabbage plants were both sprayed and dusted with D.D.T. One half were kept in a covered insectary and the remainder were subjected to weathering for different periods. 1·9 inches of rain fell in the 28 days of the experiment. The effects were tested in the following ways: (i) The plants, weathered and unweathered, together with unsprayed controls were enclosed with the moths of *Plutella maculipennis*.

* The concentration giving a kill of 50 per cent.

The moths were not inhibited from egg-laying. Many small larvae were lost, but it was clear that although some loss of toxicity occurred after two to three weeks there was still a marked lethal effect after three or four weeks. (ii) By placing on each of the treated and untreated cabbages 10 mature and 10 young larvae. Marked toxicity and repellency persisted for four weeks but with some decline in the weathered plants after two weeks. The mature larvae were the more resistant. (iii) By placing portions cut from the leaves in closed dishes with 5 mature and 5 small larvae. The mature larvae were not materially affected by the foliage of plants exposed to weathering for four weeks, among the small ones a few were still affected, but there was a definite decline in toxicity in the case of the sprayed and exposed plants after three weeks' exposure.

The growth of new foliage in these experiments seriously affected the protective power, and a critical series of stomach-poison tests in Way's apparatus, while confirming that some insecticidal action persisted after three weeks of weathering, showed that the inner (new) leaves had no toxic effect after 14 and 31 days. The decline in toxic activity of the treated cabbages with time does not appear to depend entirely on rainfall. Whether there is absorption of D.D.T. or loss by volatility in addition to attenuation by leaf growth requires investigation. It is clear that for some little time protection against caterpillars is afforded by D.D.T. when sprayed or dusted on to foliage, even when exposed to relatively heavy rainfall.

(*d*) *Field trials*

By arrangement with Dr. Mann a number of experiments with D.D.T. were carried out on vegetable plots at Woburn, others were arranged at outside centres. Dr. C. Potter and Mr. J. F. Perkins of the Plant Pathological Laboratory of the Ministry of Agriculture were responsible for the application of the dusts and sprays and for the determination of the effects. The experiments covered a variety of both crops and pests and the information obtained, although not based on statistical examination, was very comprehensive. There was very marked evidence that, so far as farm and market-garden pests are concerned, D.D.T. is very selective in its action. It is not a cure-all. Thus whereas cabbage caterpillars of all kinds were susceptible and readily controlled by it the cabbage aphis proved more resistant. Mustard beetle (*Phaedon cochleariae*) and pollen beetles (*Meligethes* spp.) were controlled by D.D.T., but the weevil *Ceutorrhynchus assimilis* was not affected. Good control of collar aphides and good protection against carrot fly (*Psila rosae*) were obtained on carrots. Good protection against bean weevil (*Sitona* spp.) was obtained, but poor control of bean aphis (*Aphis fabae*) was achieved by D.D.T. *Aphis sambuci* on elder was, however, susceptible. With the glasshouse red spider (*Tetranychus telarius*) there was neither any control nor any protection : the brown scale (*Lecanium corni*) seemed equally resistant. Among insect parasites and predators Coccinellid adults and numerous parasitic Hymenoptera were killed, but Syrphid larvae (Hover fly) were unaffected. Egg-laying by *Pieris rapae* (small cabbage-white butterfly) was not prevented.

Plant insecticides

We received a small consignment of Chinese plants from Professor Chiu of the Sun Yat Sen University through Dr. Needham, of the British Council. The work was undertaken with the approval of the Secretary of the Agricultural Research Council (the late Dr. Topley). The correct nomenclature of all but one of the plants, which was in powder form, was confirmed at Kew, through the kindness of Sir E. J. Salisbury. The samples were; *Rhododendrum molle* (flowers and root), *Milletia pachycarpa* (root and seed), *Tripterygium exesum* (root—bark powder), *Chrysanthemum cinerariifolium* (pyrethrum flowers), *Derris fordii* (root). The samples were too small for us to do more than preliminary sorting out tests, but we were able to carry out a sufficient number of tests to indicate which of the plants were worth further examination and detailed study. These proved to be *Milletia pachycarpa* (both root and seed), and *Derris fordii* (root), both containing principles of the rotenone class. They would, however, need much improvement by selection to compete in the world's markets with derris and lonchocarpus roots of pre-war standard. *Tripterygium exesum*, despite a certain reputation as a Chinese insecticide, proved disappointing, but as we learned from Sir E. J. Salisbury that a plant or two of *T. wilfordii*, probably the correct title for this plant, are kept at Kew, if anything further of interest arises in connection with it, a small supply is available. The pyrethrum was of medium quality: it is not a Chinese plant, but in view of the world shortage of this insecticide and a possible need in India and Burma its increased production might be worthwhile. It contained 0·44 per cent. Pyr.I and 0·37 per cent. Pyr.II 0·8 per cent. total pyrethrins against 1·3 to 1·6 per cent. for Kenya material.

Effect of environment on the susceptibility of insects to insecticides

Owing to pressure of other work little opportunity for carrying on this work intensively presented itself. But using the pyrethrins, lauryl thiocyanate, nicotine and dinitro-*o*-cresol, D.D.T. and Wakefield white oil against the test-subject *Tribolium castaneum* Hbst., it was shown that while a short period of cooling before spraying had little or no effect on this insect's resistance, cool conditions after treatment increased the toxicity of all the poisons except petroleum oil, in which case there was some increase in insecticidal potency with rise of temperature. Trials were carried out in both oil and aqueous media and although, in the absence of facilities for controlling both temperature and humidity, no very definite differentiations between the effect of these two factors could be made, it was clear that conditions after treatment had an important effect on both the absolute and relative toxicity of contact poisons, and that if any advance is to be made in this important subject a more detailed investigation will have to be made, in the course of which relative humidity as well as temperature will have to be brought into the picture.

Laboratory methods for testing insecticides

Investigations of techniques suitable for evaluating stomach poisons. After devising small wooden frames in which larvae could be con-

fined with a strip leaf, but in such a way that only the mouth parts of the insect could be brought into contact with its food and any poisons associated with it, attention was given to means for depositing on the food, as evenly as possible, a layer of poison. This was accomplished by means of a tall spray tower, into which the insecticide was atomised. After an interval of time during which the larger droplets were deposited, a shutter was pulled out and the deposit of fine droplets (settling mist) fell on the strips of foliage underneath. The amount of deposit per unit area was determined by the increases in weight of strips of aluminium of known area and weight placed on the stage with the foliage. The treated strips of leaf were cut into sections of known area and presented to the larvae, previously weighed, in the apparatus described. The area of leaf eaten by the larvae was determined by inspection under the microscope, and the insects were set aside in tubes in a constant temperature and humidity chamber for a period of time. The number dying and pupating was determined and correlated with the dosage per body weight. Using the instrument Mr. Way estimated that D.D.T. is about ten times as toxic as lead arsenate to *Plutella maculipennis*.

At intervals during the year a preliminary study was made of a laboratory dusting technique. A certain amount of progress has been made, but it is clear that the uniformity of the deposit and its replication will not be very easily achieved. Modifications in the technique may have to be introduced, depending on whether foliage or insect has to be dusted for use in evaluating contact or stomach-poison dusts.

In both of the above methods it is clear that particle size, and probably shape, are of considerable importance, and although no serious experimental attention has been given here to this matter up to now, it is clear that for substantial progress to be made the investigation of this important subject will require one research worker's individual attention.

Provision of insects

A considerable number of insects of various species have been raised during the year. This has meant the provision of large numbers of plants. Aphides of different species proved to be somewhat difficult to rear in anything like the numbers required owing to the presence and persistence of predators. Attention, however, has been continuously given to the possibilities as test-subjects of a variety of insects in the hope that additions could be made to our growing list. Standardised rearing under electrical fluorescent lighting is being actively experimented with.

Chemical investigations

During the year 1943-44 it was shown in America that the factor used for determining pyrethrin I in pyrethrum flowers and extracts was seriously in error. This was so grave an issue to us and other insecticide workers in this country that we approached the Imperial Institute with the proposal that a conference of workers actively engaged on pyrethrum analysis should be called to consider the matter. This was done in the early

part of 1944 and a programme of work was drawn up in which the four separate laboratories, the Imperial Institute, Messrs. Stafford Allen's, University College, Southampton (Dr. Harper), and Rothamsted should independently determine the factor from a sample of the pure pyrethrin monocarboxylic acid supplied by Messrs. Stafford Allen, who had a stock in hand. The material was distributed in the form of a standard solution by the Imperial Institute. Sufficient evidence was obtained to show that the original factor proposed by Wilcoxon was some 30 per cent. in error, but a statistical analysis carried out by the Rothamsted Statistical Department demonstrated that the discrepancies between the figures obtained by the individual co-operating laboratories were so great as hardly to warrant the publication of a new factor based upon them. It was decided at a second conference at Rothamsted to repeat the co-operative experiment, and a very carefully drawn-up code of regulations for carrying out the method was drawn up.

PERIOD 1944-45

Evaluation of pyrethrin-I factor.—The programme of investigations arranged for at the conference held in the previous year was carried out by the co-operating laboratories, and the results examined by Mr. Finney of the Rothamsted Statistical Department. His finding that, despite some discrepancy, the results were in sufficiently good agreement to warrant a conference to decide upon the factor to be used, led to a further meeting at the Imperial Institute in July, 1945. After a prolonged discussion it was decided to fix the factor for routine analysis at 1 c.c. of N/100 KIO_3 solution = 5·7 mg. of pyrethrin I at normal laboratory temperatures. As, however, there was very distinct evidence of a temperature coefficient, for research and special work the temperature gradient should be taken into account.

The effect of media on toxicity.—For some years intermittent work upon the relationship of media, in which an insecticide is incorporated and applied, to its toxicity has been the subject of research. Obviously particle size in both dusts and sprays may be a correlative factor, and from this angle investigations have once more been undertaken. As D.D.T. is a potent insecticide which can be obtained pure and in definite crystalline forms, it is being used, in the first instance, as the test insecticide. A dipping method has been worked out in which the insects are subjected to the action of the test fluid by end-over-end shaking at constant temperature, but not afterwards handled. D.D.T. by appropriate means can be prepared in two distinct crystalline forms and indications have been obtained that the needle-shaped are more toxic than the plate-like crystals.

Investigations on the insecticidal value of D.D.T. (2, 2-*bis*-*p.chlorophenyl* 1, 1, 1-*trichloroethane*)

The greater part of the work of the Department was again concerned with the insecticidal value of this compound and its analogues —both in the field and laboratory.

Fieldwork

Field trials—particularly on cabbage pests—of a more thorough nature than those of the previous year were allocated to us by the sub-committee of the A.R.C. Insecticides Conference. Through the kindness of Dr. Mann plots of cabages, of both autumn and winter varieties, were handed over to our Department for plot experiments. Unfortunately, no infestation occurred, despite the presence of cabbage caterpillars in nearby gardens. Large plots, however, laid down at the Oaklands Farm Institute, St. Albans gave a clear verdict that D.D.T. exercises a high degree of control of cabbage caterpillars. The cabbage aphis (*Brevicoryne brassicae*) is only controlled by relatively high concentrations of D.D.T. which, owing to its toxic effect on parasites and predators, may possibly encourage this pest. The control of woodlice by D.D.T. was demonstrated at Woburn Abbey.

Laboratory investigations

Chemical determination of D.D.T.—For many researches on D.D.T. the determination of the amounts present is very important. Various colorimetric techniques have been suggested, but none have been so far employed in our work, since various other factors upset their accuracy. Resort had to be made both on a macro- and micro-scale to the Volhard technique for the determination of chlorine ions after their liberation by the action of alcoholic alkali from D.D.T., one chlorine ion being liberated per molecule. The macro-method has been employed to ascertain the stability of D.D.T. in the presence of a variety of chemical compounds, the micro-technique is now being used to determine the amounts of D.D.T. on foliage after the lapse of different periods of time.

Stability of D.D.T.—A knowledge of this is required if D.D.T. is to be incorporated with certain media or other insecticidal principles. It seems to be quite stable in most of the common organic solvents, and with many wetters and spreaders. Stability, however, depends chiefly on the pH of the medium, and it was carefully studied for alkalinities rising from 7 to 10. Even at so low an alkalinity as pH 7·1 there is some decomposition after 23 days, at pH 8·0 one-half, and at pH 9-10 nearly the whole, is decomposed in that time, but there is a large measure of stability over a period of 2 days for pH's ranging from 7 to 11. The organic solvent used has an important bearing on the speed and certain metals, iron, manganese and copper, catalyse decomposition. A basic insecticide like nicotine and a number of amines give rise to decomposition like other alkalies to $(Cl\ C_6H_4)_2{=}C{=}CCl_2$ which has a low insecticidal value.

Insecticidal values of the analogues of D.D.T.—A number of chemical compounds closely related to D.D.T. have been examined quantitatively in the laboratory to determine their insecticidal potency relative to D.D.T. Fluorine, bromine and iodine have been substituted in the benzene ring and combined with chloral to give compounds analogous to D.D.T., a number of chlorine compounds of varying complexity, with the halogen in the ethane bridge and in addition a number of alkyloxy benzene tri-chloroethanes have been examined, as has the hydrocarbon corresponding to D.D.T.

The relative toxicities appear to depend somewhat upon the insect used as test-subject, but it is clear that among the halides D.D.T., the chlorine compound, is the most toxic, but the bromophenyl tri-chloroethane is close to it. Differences, however, in the slope of the probit-characteristic lines make the usual methods of comparative assessment invalid. The steepness of slopes seems to be inversely correlated with molecular weight for compounds of the same molecule type; very exceptional and at present inexplicable results have been obtained with the iodine compound, iodo benzene trichloroethane. The methoxy and ethoxy benzene trichloroethanes are relatively powerful insecticides, but the propoxy compound is less so, while the butoxy and amyloxy compounds are practically devoid of insecticidal action.

The effect of leaf growth upon the toxicity of D.D.T.—As a protective insecticide D.D.T. has a considerable reputation, it is therefore of some importance to know how its toxicity persists on foliage. In 1944 it was shown that despite leaf growth and weathering D.D.T. was still relatively potent upon cabbage after some three weeks. A number of experiments with mosquitoes (a sensitive insect) have introduced a variety of queries as to the fate of D.D.T. sprayed upon leaf surfaces. Experiments were therefore carried out in the glasshouse, in which the leaf growth of cabbages and the toxicity of D.D.T.-sprayed leaves at various stages of growth were determined. Chemical determination of the deposits upon the foliage is still required for completeness, but from the experiments to date the growth of the cabbage leaf, when protected from the weather, has a less depreciative effect upon toxicity than one would expect. If anything, toxicity appears to be enhanced. This may possibly be due to the waxes associated with brassicae foliage.

Effect of particle size and shape upon toxicity.—The cabbage caterpillar *Plutella maculipennis* was used as in the previous experiment to test these factors. It was found that the needle-shaped crystals ($100 \times 2\ \mu$) were more effective than the plate-like crystals ($40 \times 8\ \mu$) and that when D.D.T. was applied emulsified in olive or heavy-petroleum oil its toxicity was materially increased.

Experiments on the effect of D.D.T. on entomophagous insects.—Some concern has been expressed concerning the possible ill effects upon beneficial insects, parasites, and predators. Field observations in 1944 had shown that the results varied with the species, and laboratory experiments were therefore undertaken particularly with those entomophagous insects likely to be of importance in the control of cabbage pests, the aphis *Brevicoryne brassicae* and various caterpillars. Cabbages sprayed and dusted with D.D.T. preparations were enclosed in cages with the appropriate insect. In general, the insecticide exerted very little repellency and the final results of day-to-day examinations were;—

Various Syrphidae mainly *Syrphus ribesii*, adults.

	D.D.T.	Killed
Spray suspension ..	0·01%	7%
Spray suspension ..	0·1%	100%
Commercial spray ..	0·2%	21%
Commercial dust ..	5·0%	71%

Although the data are incomplete, little effect on the Syrphid larvae seems to have been observed, but all the Eristalis adults

were dead in two days. There is thus some reason for believing that although high concentrations of D.D.T. will exercise some control of *B. brassicae*, the cabbage aphis, if an attack of such predators as the above has already well developed, spraying and dusting with D.D.T. against this pest might well do harm.

In the case of the lady-bird species of Coccinellidae, the suspension of pure D.D.T. had only a relatively low toxic effect, but the commercial dust and spray were highly toxic. The hymenopterous parasites of *B. brassicae*, mainly adults of *Aphidius brevicornis*, were relatively susceptible, particularly to the suspension of pure D.D.T. micro-crystals, and the adults of the parasite of *Pieris brassacae*, *Apanteles glomeratus*, were completely wiped out by all the D.D.T. preparations, even at low concentrations. Thus there is some risk as far as cabbage pests are concerned that the partial control exercised by natural insect enemies might be interfered with.

Effect of D.D.T. on plants.—The phytocidal effect, if any, of an insecticide may seriously limit its usefulness, such an effect may also be accentuated by the medium in which it is incorporated and thus restrict means of application. In view of this a number of trials were made upon a few selected market-garden plants. A carefully devised series of experiments on tomatoes showed that this plant was relatively resistant although some foliage scorch occurred and an apparent drop in yield after the application of a commercial spray, but no effect on size of fruit, ripening or flavour was observed. Cabbages were quite immune, and hearted normally, but if dipped in an emulsion containing benzene showed severe scorching although the yield was normal.

Cucumbers and vegetable marrows showed definite injury. In the case of the cucumbers there was scorch, and with the marrows leaf curl, and both showed interveinal yellowing. Cucumbers, however, appeared to yield normally. Lettuces, radishes, turnips, peas, runner beans, French beans, broad beans and carrots showed no injury.

Toxicity to bees.—Conjoint work with the Bee Department indicated that apparently the effect of D.D.T. upon bees varies with the conditions and mode of application ; as a contact poison D.D.T. is fairly highly toxic, but its stomach action is less marked than was to be expected, nor does it appear to be highly injurious to foragers on sprayed blossoms, but as no information was obtained as to effects on bee larvae, the status of D.D.T. as a bee poison needs establishing by further work.

PUBLICATIONS

1. Martin, J. T., Mann, H. H. and Tattersfield, F. 1939. *The manurial requirements of pyrethrum (Chrysanthemum cinerariaefolium Trev.).* Ann. Appl. Biol., **26**, 14-24.

A small field experiment upon the manurial requirements of the insecticidal pyrethrum plant, grown upon sandy soil of low fertility, is described. Lime had the effect of producing slight, but not significant increases each year in the yield of flowers and their content of the pyrethrins, and decreased the percentages of plant failures in the fourth and fifth years of the experiment. There was a significant depression in the yield of flowers in the year after the single application of double dressings of the manures, but no effect

in later years. The yearly application of moderate dressings of manures gave significant increases in the yield of flowers in the second and fifth years, and significant increases in the pyrethrin I content of the flowers in the fourth and fifth years of the experiment.

2. TATTERSFIELD, F. 1939. *Biological methods of testing insecticides.* Ann. Appl. Biol., **26**, 365-384.

A detailed review of the biological methods used in the quantitative laboratory evaluation of insecticides. Contact insecticides, stomach poisons and fumigants are briefly dealt with and some consideration is given to the methods of assessing results. A bibliography of 87 references is appended.

3. MARTIN, J. T. and TATTERSFIELD, F. 1939. *The trend of progress—insecticides.* Chem. Ind., **17**, 635-640.

A contribution to the Symposium on the Trend of Progress at the Annual Meeting of the Society of Chemical Industry, 1939. A brief review is given of the work carried out in the several fields of research, including stomach poisons both inorganic and organic, contact insecticides of vegetable origin or derived by synthesis. Recent work on the moth-proofing of fabrics is briefly dealt with. An outline is given of present tendencies in research.

4. MARTIN, J. T. 1939. *Agricultural insecticides.* Manufacturing Chemist, **10**, 41-46.

A general account is given of the sources of supply and chemistry of the species of Derris and Pyrethrum now widely used as insecticides. Instances of the successful use of these materials against specific pests of crops and livestock are cited.

5. HARPER, S. H. 1939. *The active principles of leguminous fish-poison plants. Part I. The properties of l-a-toxicarol isolated from* Derris malaccensis *Kinta-type.* J. Chem. Soc., 812-816.

The optically active precursor of toxicarol is obtained by direct crystallisation of an ethereal extract of *D. malaccensis* (Kinta-type). After freeing from a small proportion of sumatrol by the method of Cahn, Phipers, and Boam (1938), the *l-a*-toxicarol was identical in properties with that described by Tattersfield and Martin (1937). It is concluded that the optical data of Cahn, Phipers, and Boam are incorrect, and their criticism of Tattersfield and Martin unjustified.

6(*a*) HARPER, S. H. 1939. *The precursor of Buckley's compound.* Chem. Ind. **58**, 292. A letter announcing discovery.

6(*b*) HARPER, S. H. 1939. *The active principles of leguminous fish-poison plants. Part II. The isolation of l-elliptone from* Derris elliptica. J. Chem. Soc., 1099-1105.

An optically active substance, *l*-elliptone isolated from the neutral rotenone-free resin from *D. elliptica* (var. Sarawak creeping), is shown to be the precursor in the resin of Buckley's substance. From a study of its reactions and by comparison of these with the reactions of isorotenone, a structure is suggested for elliptone.

7. HARPER, S. H. 1939. *The active principles of leguminous fish-poison plants. Part III. The structure of elliptone.* J. Chem. Soc., 1424-1427.

The structure advanced for elliptone in Part II is placed beyond doubt by degradation experiments. Dehydroelliptone with zinc and alkali yields elliptic acid, oxidation of which with alkaline hydrogen peroxide gives derric acid. This establishes the identity of rings A, B, and C with those of rotenone and iso-rotenone. *l*-Elliptone with alcoholic alkali gives 4-hydroxycoumarone-5-carboxylic acid, whereas iso-rotenone under the same conditions gives 4-hydroxy-2-isopropylcoumarone 5-carboxylic acid (isotubaic acid). This establishes the nature of rings D and E and hence that of the whole molecule.

8. TATTERSFIELD, F. and POTTER, C. 1940. *The insecticidal properties of certain species of Annona and of an Indian strain of* Mundulea sericea (*Supli*). Ann. Appl. Biol., **27**, 262-273.

Laboratory insecticidal trials, made with several species of Annona, *A. muricata*, *A. palustris*, *A. reticulata*, *A. squamosa*, show that plants of this genus possess contact insecticidal properties to aphides. *A. reticulata* was the most potent of those tested. Seed, root, leaf and to a less extent the stem of this species possessed contact insecticidal properties. The seed of *A. muricata* and the leaves of *A. squamosa* and *palustris* also showed contact toxicity, but were not so potent as *A. reticulata*. The seed of *A. squamosa* was not available for testing purposes. None of the above are superior to the leaf, root and bark of *Mundulea sericea* Wild. of the variety known in India as 'Supli' and are much less toxic than the richer specimens of Derris elliptica root such as Changi No. 3.

The toxic action of the Annona spp. appears to be rather specific. Aphides are susceptible, but *Oryzaephilus surinamensis* L., which is susceptible to the rotenone class of insecticides, is resistant.

Tests made with extracts of a variety of *Mundulea sericea* Wild. from India showed that leaf, bark and root possessed marked insecticidal properties when tested on *Macrosiphoniella sanborni*, and *Oryzaephilus surinamensis*. This is in contrast with the African variety, the leaf and root of which are reported as distinctly less potent than the bark. The toxicity of none of these parts is of the same order as that of the root of *Derris elliptica*, Changi No. 3.

9. MARTIN, J. T. 1940. *The problem of the evaluation of rotenone-containing plants. V. The relative toxicity of different species of derris.* Ann. Appl. Biol, **27**, 274-294.

The relative toxicities to *Aphis rumicis* of different species and varieties of derris root have been determined. A *Derris elliptica*, Changi root, was two and one-half times, a *D. malaccensis*, Sarawak ens root, was one and three-quarter times, and a *D. elliptica*, Sarawak-creeping, root, was one and one-quarter times as toxic as a *D. malaccensis*, Kinta, root.

Preliminary trials showed that the relative toxicities of three of the roots to a stored products insect, *Oryzaephilus surinamensis*, were of a similar order. All toxicity data have been subjected to statistical analysis.

Various methods suggested for the chemical evaluation of Derris have been examined and discussed. Methods based upon optical rotation values have been shown to fail in the evaluation of roots and resins of different species, while the method of Jones and Smith (1936), in which a definite toxic value is given to the non-rotenone fraction of the derris extract, has been found to be inadequate when applied to the roots under consideration.

The determination of the percentage "rotenone equivalent" values of the roots, based upon the alkaline fractionation of the resins and the toxicities of the deguelin and toxicarol fractions relative to that of rotenone, has given a reasonably close estimate of the toxicities of the derris roots examined. The application of the method to the assessment of the toxic value of derris resins is described.

10. HARPER, S. H. 1940. *The active principles of leguminous fish-poison plants.* Part IV. *The isolation of malaccol, from* Derris malaccensis. J. Chem. Soc., 309-314.

An optically active phenol, malaccol, isolated from an ethereal extract of the root of *Derris malaccensis* (Kinta type) is shown to have the formula $C_{30}H_{16}O_7$. From a study of its reaction and by comparison of these with the reactions of sumatrol and of elliptone, the structure 15-hydroxyelliptone, is suggested for malaccol.

11. HARPER, S. H. 1940. *The active principles of leguminous fish-poison plants. Part* V. Derris malaccensis *and* Tephrosia toxicaria. J. Chem. Soc., 1178-1184.

The resin from *D. malaccensis* root has been fractionated by chemical means and *l-a*-toxicarol obtained in a pure condition. In addition, rotenone, elliptone, deguelin, malaccol, sumatrol, and a new phenol have been isolated. The properties of this phenol, which is isomeric with toxicarol, are discussed and as a working hypothesis an isoflavone structure is suggested.

12. Tattersfield, F., Martin, J. T. and Howes, F. N. 1940. *Some fish-poison plants and their insecticidal properties.* Kew Bull. Misc. Inf., No. 5, 169.

The distribution, native uses, and contact insecticidal properties of a number of fish-poisoning plants are described. None is of the same order of effectiveness as *Derris elliptica*. The most interesting from an insecticidal point of view are a vine from the British Solomon Islands, indistinguishable from Derris *trifoliata*, the leaves of which are toxic, *Dolichos pseudopachyrhizus* from Kenya, *Milletia pachycarpa*, from India, *Tephrosia macropoda* from Natal and *T. vogelii* from Uganda.

13. Martin, J. T. and Hester, K. H. C. 1941. *Dermatitis caused by insecticidal pyrethrum flowers* (Chrysanthemum cinerariifolium). Brit. J. Dermatology and Syphilis, **53**, 127-142.

Patch tests of powdered and dissected pyrethrum flowers have been carried out. The causal agent, or agents, of the dermatitis appears to be concentrated in the lower parts of the flower-head. Powdered flowers moistened with water gave a more intense reaction than the air-dried ground flowers. Pollen separated from the flowers gave only a slight reaction.

Ether and petroleum ether extracts of the flowers have been fractionated and a number of products tested for their ability to produce dermatitis. A colourless extract, obtained by petroleum ether extraction of the flowers mixed with charcoal, gave an intense reaction. The pyrethrins, tested in a concentrate containing 93 per cent. of apparent pyrethrins as determined by a modified Seil method, are shown to be devoid of dermatitis-producing properties.

The volatile oil, obtained by steam distillation of powdered flowers, is shown to be highly active. The oil after the extraction of a volatile acid fraction with alkali gave a less intense reaction, while the steam-distilled flowers also gave a positive reaction. The possibility that crystalline constituents of the petroleum ether extract of the flowers are contributory causal agents of the dermatitis is indicated.

14. Potter, C. 1941. *A laboratory spraying apparatus and technique for investigating the action of contact insecticides with some notes on suitable test subjects.* Ann. Appl. Biol., **28**, 142-169.

An outline of the general problem of the evaluation of liquid contact insecticides is given. A summary of the laboratory methods of evaluation already described and the reasons for the adoption of the procedure described are outlined. An account is given of the development of the spraying apparatus together with experiments on factors likely to cause variation in the replication and distribution of the deposit. The apparatus finally adopted is described and data are presented on its physical performance. The selection and rearing of test insects is described. An account is given of the factors in the technique which may cause errors in the determination of the dosage-mortality data, with some experiments. The technique at present adopted is described, with examples of the dosage-mortality curves obtained.

15. Martin, J. T. 1941. *The chemical evaluation of pyrethrum flowers* (Chrysanthemum cinerariifolium). *The extraction of the flowers for analysis and the preparation of colourless concentrates of the pyrethrins.* J. Agric. Sci., **31**, 178-185.

Biological trials have been carried out to determine the efficacy of petroleum ether as solvent for the extraction of pyrethrum flowers for analysis. Ninety-five per cent of the toxic material was extracted from flowers one year old after only 3 hr. percolation. An extraction period of 8 hr. with petroleum ether is suggested.

A method of preparing colourless extracts of pyrethrum and analytical data for such extracts are given. They are shown to be of value for the preparation of concentrates of the pyrethrins. The preparation of a colourless concentrate containing 93 per cent of total pyrethrins, as determined by a modified Seil method, is described.

16. MARTIN, J. T. 1942. *The problem of the evaluation of rotenone-containing plants.* VI. *The toxicity of* l-*elliptone and of poisons applied jointly, with further observations on the rotenone equivalent method of assessing the toxicity of derris root.* Ann. Appl. Biol., **29**, 69-81.

The assessment of toxicity by the determination of the rotenone equivalent has been shown successfully to apply to four of the derris roots examined earlier in this series of investigations. Observations on the stability of the resins in ground roots stored in tins at room temperatures have been recorded. *l*-Elliptone has been shown to be one-fifth as toxic as rotenone to *Macrosiphoniella sanborni* when tested in an alcohol-saponin medium. The toxicities of poisons applied jointly have been examined. The observed toxicities of mixtures of rotenone with a deguelin concentrate, *l*-elliptone and *l*-α-toxicarol have been compared with those predicted from the potencies of the constituent poisons. No significant synergistic or antagonistic effect has been found. The bearing of this upon the validity of the rotenone equivalent method of assessing toxicity has been discussed.

17. COOMBER, H. E., MARTIN, J. T. and HARPER, S. H. 1942. *The determination of rotenone in derris root.* J. Soc. Chem. Ind., **61**, 110-112.

An improved method for estimating rotenone in derris root, employing the carbon tetrachloride complex separation is described. It has been shown by the three groups of workers to give concordant results with various types of root. Methods of determining moisture content and chloroform extract are also given. Their adoption in the United Kingdom as standard methods is recommended.

18. HARPER, S. H. 1942. *The active principles of leguminous fish-poison plants. Part* VI. *Robustic acid.* J. Chem. Soc., 181.

A substance isolated from the ethereal extract of *Derris robusta* has been shown to be a mono-carboxylic acid, $C_{27}H_{24}O_8$ (less probably $C_{28}H_{26}O_8$) containing two methoxyl groups, to which the name robustic acid has been given. It is probably related to lonchocarpic acid $C_{26}H_{26}O_6$ a mono-carboxylic acid containing one methoxyl group isolated by Jones (J. Amer. Chem. Soc., 1934, **56**, 1,247) from a species of Lonchocarpus, as they both give the same sequence of colour change in the Durham test.

19. HARPER, S. H. 1942. *The active principles of leguminous fish-poison plants. Part* VII. *The reduction of elliptone.* J. Chem. Soc., 587-593.

The course of the reduction of *l* and *dl*-elliptone in acetic acid over platinum oxide catalyst has been elucidated, and the following stages characterised : dihydroelliptone, dihydrodeoxyelliptone, octahydrodeoxyelliptone and perhydroelliptone.

The zinc-alkali reduction of the dehydro-compounds has been shown to give in addition to the acids of the derrisic acid type, phenols analogous to derritol.

Oxidation of elliptone with nitrous acid has given elliptonone, a diketone, whose structure has been established by a partial synthesis from elliptol, the phenol obtained in the zinc-alkali reduction of dehydroelliptone.

Biological trials using chrysanthemum aphis as test insect have shown that *l*-elliptone is, next to rotenone, the most toxic insecticidal substance to be isolated from Derris resin in an optically active form. In the order of decreasing toxicity ; *l*-elliptone>*dl*-elliptone>*l*-dihydroelliptone>*dl*-dihydroelliptone.

20. HARPER, S. H. 1942. *The active principles of leguminous fish-poison plants. Part* VIII. *The synthesis of dehydrotetrahydroelliptone and of dehydrotetrahydromalaccol.* J. Chem. Soc., 593-595.

Condensation of methyl-2-cyanomethyl-4 ; 5-dimethoxyphenoxyacetate with 2-ethylresorcinol by the Hoesch method and subsequent hydrolysis gave rise to tetrahydroelliptic acid. Cyclisation of this acid with hot acetic anhydride and sodium acetate furnished through the acetate dehydrotetrahydroelliptone identical with that prepared from elliptone. The formula established for elliptone by degradative experiments (J., 1939, 1,424) has therefore been fully substantiated.

By an analogous condensation with ethylphloroglucinol, tetrahydromalacolic acid was prepared. This acid on cyclisation gave dehydrotetrahydromalacol, for which an angular and a linear formula are possible. It has not proved possible however to compare this product with that derived from natural sources.

21. HARPER, S. H. 1942. *The active principles of leguminous fish-poison plants. Part* IX. *The synthesis of furanoisoflavones related to rotenone.* J. Chem. Soc., 595-598.

By utilising the method of Venkataraman *et al.* (J., 1934, 513, 1,120, 1,769) isoflavones have been prepared from the methyl ethers of derritol, isoderritol and elliptol. In the case of the last by the isolation of a crystalline intermediate, it is shown that the reaction does not proceed directly to the isoflavone but occurs through the formation of an isoflavanonol and its subsequent dehydration. *iso*Flavones of this type have been postulated as likely to occur in Derris resin along with rotenone and elliptone, with which they are isomeric.

These *iso*flavones are remarkable in giving a positive Durham test, previously regarded as specific for the rotenoids. Their reactions have been studied, and a method devised for the detection of the formic acid formed in their hydrolysis. This method has been applied to the " toxicarol *iso*flavone " isolated from crude toxicarol to establish conclusively its *iso*flavone nature and hence support for the formula previously suggested (J., 1940, 1,178).

22. COOMBER, H. E., MARTIN, J. T. and HARPER, S. H. 1943. *The determination of rotenone in derris root. A reply.* J. Soc. Chem. Ind., **62**, 73-75.

The criticism by Edwards of the method established by the authors for determining rotenone is answered. The position with regard to sampling derris consignments is discussed, and the need for the improvement of sampling methods is shown. Objections to the method of analysis given by Edwards are stated.

23. TATTERSFIELD, F. and POTTER, C. 1943. *Biological methods of determining the insecticidal values of pyrethrum preparations* (*particularly extracts in heavy oil*). Ann. Appl. Biol., **30**, 259-279.

Pyrethrum extracts in non-volatile oil carriers are effective insecticides in the field because they act as a direct spray killing the insect and also form a toxic film over which the insect crawls. It is necessary to study both these effects for a complete laboratory assessment of toxicity. Suitable laboratory techniques and methods for the assessment of results are described together with an account of experiments on the effect of various factors on the insecticidal efficiency of pyrethrum-in-oil preparations, both as direct sprays and as toxic films.

24. MARTIN, J. T. 1943. *The preparation of a standard pyrethrum extract in heavy mineral oil, with observations on the relative toxicities of the pyrethrins in oil and aqueous media.* Ann. Appl. Biol., **30**, 293-300.

The preparation of a pyrethrum extract in highly refined heavy mineral oil, suitable for use as a basis of reference in the biological evaluation of commercial pyrethrum-heavy oil preparation, is described. The solution was standardised with respect to colour, resin content and equal proportions of the pyrethrins. A standard solution containing pyrocatechol remained stable, when judged by the chemical determination of the pyrethrins, over a period of months.

When applied in heavy mineral-oil medium, pyrethrin II was shown to possess a toxicity to *Tribolium castaneum* Hbst., approaching, if not equal to, that of pyrethrin I. When applied in an aqueous medium the toxicity of pyrethrin II was very much lower than that of pyrethrin I.

25. POTTER, C. and TATTERSFIELD, F. 1943. *Ovicidal properties of certain insecticides of plant origin.* (*Nicotine, pyrethrins, derris products.*) Bull. Entom. Res., **34**, 225-244.

The pyrethrins, nicotine, rotenone and a derris resin have been tested in the laboratory under standard conditions for their ovicidal effect. The test-subjects were: *Pieris brassicae, Plutella maculipennis, Aphis rhamni, Ephestia kühniella* and *Sitotroga cerealella.* Notes on the technique of egg production are given for these species. In the majority of the tests made a water medium containing acetone together with sulphonated lorol as a wetting agent was used.

It has been shown that all these products are toxic to the species on which they were tested. Lauryl thiocyanate, β-butoxy β-thiocyanodiethyl ether and 3 : 5 dinitro-*o*-cresol were included as substances of recognised ovicidal value for the purposes of comparison.

All the above insecticides derived from plants compared favourably in their toxic action with the synthetics. In two instances during tests on eggs of *Ephestia kühniella*, data were obtained enabling a satisfactory statistical comparison of relative potency to be made. In the first of these the pyrethrins were found to be $8 \cdot 45 \pm 1 \cdot 47$ times as toxic as 3 : 5 dinitro-*o*-cresol, while in the second the pyrethrins were found to be $2 \cdot 66 \pm 0 \cdot 26$ times as toxic as *Derris elliptica* resin (rotenone contents 37-40 per cent.). It therefore appears that both the pyrethrins and the derris resin were more toxic, weight for weight, than 3 : 5 dinitro-*o*-cresol which is recognised as one of the most potent ovicides.

The above vegetable poisons were found to be toxic not only to eggs developing in a few days without a diapause, but also to those of *Aphis rhamni*, a species of overwintering egg. The tests on *A. rhamni* were made at the time the eggs were just starting to hatch. The same result might not have been obtained with eggs at an earlier stage of development.

Observations were made on the effect of the different insecticides on the development of the egg. This effect appeared to differ with each substance, either qualitatively or quantitatively, but within the limits of the experiment it seemed to be independent of the species of the egg.

26. Dion, W. M. and Lord, K. A. 1944. *A comparison of the toxicity of certain dyestuffs to the conidia of* Fusarium culmorum. Ann. Appl. Biol., **31**, 221-231.

The toxicity of a number of dyestuffs to the spores of *Fusarium culmorum* and *Cercosporella herpotrichoides* was determined by the slide-germination technique. No attempt was made to distinguish between fungistatic and fungicidal activity.

The toxicity of basic dyestuffs was unaffected by the acid radicle associated with the dye base.

The high toxicity to *Fusarium culmorum* of malachite green dye base was reduced weight for weight and mole for mole by substitution of ethyl, propyl or butyl groups for methyl groups.

The reduction of malachite green to malachite green leuco base removed toxicity.

The substitution of amino groups and alkylated amino groups in benzene nuclei of triphenyl methane increased toxicity, whereas acid groups reduced toxicity. Sulphonation and carboxylation reduced toxicity to vanishing point.

Alkylation of amino groups increased, but alkylation of benzene nuclei did not affect toxicity appreciably.

When the central carbon atom of the triphenylmethane dyestuffs was replaced by nitrogen (e.g., Bindschedler's green) the diphenyl ammonium compounds were less toxic than the corresponding triphenyl methane compounds.

The prevention of rotation of the aminated benzene rings by bridging, in the o-position to central atom, with O or N, and so obtaining a planar molecule only slightly affected toxicity.

Certain acid dyes stimulated fungal growth.

The toxicity of the basic dyestuffs seems to depend not on one specific part but on the molecule as a whole, and within certain limits the structure may be varied without pronounced changes in toxicity.

REPORTS

1939-1945

TATTERSFIELD, F. and POTTER, C. *The insecticidal properties of a synthetic organic insecticide.* Report to the Ministry of Agriculture.
TATTERSFIELD, F. and LORD, K. A. *The preparation of dermatitis-free pyrethrum extracts.* Report to the Ministry of Production.
TATTERSFIELD, F. Report to the British Council upon Preliminary Tests of Chinese Plants for their Insecticidal Properties.
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MARTIN, J. T. *Laboratory procedures in the studies of the chemical control of insects,* edited by Campbell, F. L. and Moulton, F. R., "English and European Methods of Testing Stomach Poisons," pp. 102-104. 1943. American Association for the Advancement of Science.
TATTERSFIELD, F. *A survey of insecticide materials of vegetable origin,* edited by Holman, H. J., B.Sc., A.R.C.S., D.I.C., A.I.C. Issued under the auspices of the consultative committee of insecticide materials of vegetable origin. London : Published by the Imperial Institute. 1940.
TATTERSFIELD, F. Article on Insecticides in *What Industry owes to Chemical Science,* 3rd Ed. 1940. Heffer, Cambridge.

FIELD EXPERIMENTS ON THE ROTHAMSTED FARM

By E. M. Crowther, H. V. Garner, J. R. Moffatt, D. J. Watson and F. Yates.*

During the war years there has been a steady expansion of field experimentation. The number of plots was about 1,200 in 1939, and has increased each year to over 1,700 in 1945. The selection of suitable sites has become increasingly difficult, for it is the practice to allow an interval of at least three years between successive experiments on the same site, so that residual effects of treatments may be minimised, and the choice of site for many experiments is restricted by special soil requirements. Fortunately, the ploughing-up of many of the old grass fields has provided new areas for experiments on arable crops.

There are three groups of field experiments ;—

(1) *the classical experiments*, begun by Lawes and Gilbert. In all but one of these the cropping and manuring of the plots continues unchanged from year to year. The exception is Agdell, where a four-course rotation is followed.

(2) *the modern long-period experiments*, which are concerned either with the persistence or accumulation of treatment effects over a number of years, or with variation in the effect of treatment in relation to seasonal weather conditions.

(3) *the annual experiments*, in which treatment effects are tested only in one year, except that in a few of them the immediate residual effects in the following year are also measured. The annual experiments may be repeated a number of times, on a fresh site each year.

The problems investigated are listed below with cross references to the reports of the departments primarily concerned. Many of the experiments form part of series carried out at a number of centres on a co-ordinated plan.

The classical experiments

Broadbalk, continuous wheat. The hundredth successive wheat crop in this experiment was harvested in 1943. No recent changes have been made. The fallowing of one fifth of the field annually, begun in 1931, has been continued, and has justified itself as a method of weed control, although it is not effective against wild oat (mainly *Avena ludoviciana*), which is particularly abundant on the farmyard-manure plot. Slender foxtail is still prevalent over the whole field.

Hoosfield, alternate wheat and fallow. The modification of this experiment introduced in 1932, which provides a comparison of a one-year fallow with a three-year fallow, has been continued. Wheat bulb-fly has occasionally caused loss of plant on these plots.

Hoosfield, continuous barley. Weed infestation has become a serious problem on this field, the dominant species being charlock and wild oat (*A. fatua*). The infestation was so bad in 1943 that the

* These members of the staff constitute the Field Plots Executive Committee and are responsible for planning and carrying out the programme of field experiments.

plots were fallowed in the following year. This caused some reduction of the charlock population, but was quite ineffective against wild oat. In 1945 the crop was sprayed with D.N.O.C. to eradicate the charlock, and this treatment will be repeated annually when necessary.

Various methods of controlling wild oat on Broadbalk and Hoosfield have been considered, and the only one likely to be effective, which will not interfere with the continued cropping of the plots, appears to be hand-pulling at the time when the emergence of the panicles makes it easy to distinguish the oats from the wheat or barley. It is intended to make an effort in 1946 to clean the fields by this method, and, on Hoosfield, by intensive cultivation during the period between harvesting and sowing.

Barnfield, continuous mangolds. It was discovered in October, 1944 that beet eelworm is present on the plots of Barnfield. Where it came from, and how long it has been present on the field, are not known. There is some slight evidence that the yield on some plots is beginning to suffer. The infestation is more severe on the west side on and near to the farmyard-manure plots than in the rest of the field, and this suggests that it came in with the farmyard manure. If so, the original infestation probably entered the field before 1928, which was the last year in which London dung was used. Since that year dung produced on the farm has been used exclusively, and there is apparently no source of infection outside Barnfield, for a careful search has failed to reveal the presence of eelworm in any other susceptible crops on the farm. The present serious infestation is probably a recent development, for a search for eelworm made a few years ago gave negative results. Permission to continue cropping the field with mangolds has been obtained, and the future development of the infestation will be carefully watched.

Agdell, four-course rotation experiment. Parts of this field are now very acid, and heavily infected with club-root. For this reason the root crops in 1940 and 1944 were almost complete failures. In 1940 yellow turnips of the Bruce variety, and in 1944 a number of different strains of turnips and swedes were grown. Differences in susceptibility to club-root were detected, but none of the varieties was sufficiently resistant to withstand completely the very intense infection present in the field. The other crops in the rotation continue to give good yields.

Park Grass plots, permanent grass cut for hay. There have been no outstanding changes in the herbage on these plots in recent years. Early in the war, complete botanical analysis of samples of the herbage had to be discontinued owing to lack of staff, but partial analyses on a selection of the more interesting plots have been made annually.

Long-period experiments

Town refuse.—Cumulative and residual effects of various forms of town dust-bin refuse are compared with those of farmyard manure in an experiment begun in 1940. The cropping has varied from year to year, but not in a regular rotation, and has included sugar beet, mangolds, beans, barley and wheat. The manurial value of the town refuse was low, as in parallel experiments at Tunstall, Saxmundham and elsewhere. (Chemistry.)

Four-course rotation experiment on residual values (see Rothamsted Annual Report, 1931, p. 129).—This experiment, started in 1930, tests the immediate and residual effects of three bulky manures—farmyard manure, straw compost and chaffed straw—and two phosphate fertilisers—superphosphate and Gafsa mineral phosphate—applied at intervals of five years to plots in a four-course rotation ; wheat, potatoes, barley, rye-grass. One set of applications is made every year to appropriate plots for each crop, the treatments repeating on the same plot every fifth year. The farmyard manure and straw compost supply equal amounts of organic matter, and the chaffed straw is used in amounts equal to those required to make the straw compost. Fertilisers are added with the organic manures to raise the total nitrogen, phosphate and potash to constant amounts. The two phosphate fertilisers are applied every five years in amounts equivalent to the total phosphate given on the organic-manure plots, but for these treatments the nitrogen and potash fertilisers are divided so that one-fifth of the total goes on each year to each plot.

Farmyard manure and straw gave better yields of potatoes than straw compost, but the three organic manures gave similar yields of barley. For all three materials the yields fell off at first rapidly and then more slowly, the fall after the second year being shown more clearly in barley than potatoes. In the year of application the organic manures gave yields similar to those from superphosphate with one-fifth of the total amount of nitrogen and potash. Subsequently the yields from the residues of superphosphate with small annual dressings of nitrogen and potash greatly exceeded those from the residues of organic manures. Superphosphate gave consistently higher yields than mineral phosphate, which was probably ineffective on this neutral soil. The residual effect from superphosphate fell off very slowly after the second year, but was markedly less than the immediate effect in the year of application.

Three-course rotation experiment on methods of utilising straw (see Rothamsted Annual Report, 1933, p. 118).—This experiment, started in 1933, tests three methods of applying straw to land cropped in the three-course rotation ; barley, sugar beet, potatoes. Each year half the plots receive a fixed quantity of fertilisers which is given in four ways ; (1) in spring, without straw : (2) in spring, after straw ploughed-in in autumn : (3) divided between autumn and spring, after straw ploughed-in in autumn : (4) used to make straw compost which is applied in spring. In the following year the plots are treated uniformly, any additional fertiliser needed for the crop being applied equally to all plots. It should be noted that by contrast with the four-course rotation, losses of nutrients during the composting process are not made good by additional fertiliser. This experiment tests the value of straw as such, over and above that of fixed amounts of fertilisers.

The compost has consistently given poorer results than the fertilisers alone, as plant foods are locked up in unavailable forms during the composting process. Where constant amounts of fertilisers were applied in the spring, straw ploughed-in increased the yield of potatoes by about 10 cwt. per acre, but had no effect on sugar-beet roots or barley grain ; straw reduced the yield of sugar-beet

tops and barley straw. Residues of straw applied either as such or as compost improved the yields of potatoes in the second year but had little effect on other crops.

Six-course rotation experiment on seasonal variation in responses to fertiliser (see Rothamsted Annual Report, 1931, p. 131).—This experiment and an experiment of the same design at Woburn were begun in 1930. It gives information on the relative responses to fertilisers of the six crops of the rotation—barley, clover, wheat, potatoes, rye and sugar beet—on the variation in response from year to year, and on the relation between response and rate of application. The design is such that the effects of individual treatments are not cumulative, and it will, therefore, be possible to evaluate the effects of seasonal weather conditions on yield and fertiliser responses when a sufficient number of years has elapsed. A noteworthy feature of both the Rothamsted and Woburn experiments is that although no farmyard manure is given at any stage of the rotation, there is no evidence of a downward trend in yield of any of the crops during the course of the experiment.

Two-course rotation experiment on the immediate and cumulative effects of salt.—An experiment was begun in 1942 to test the effect of frequent heavy applications of salt on land cropped alternately with sugar beet and barley. So far there has been no sign of soil deterioration, and salt has given good returns, while the response to potash has been small. (Chemistry.)

Deep-cultivation rotation experiment.—The effect of deep ploughing (to 12 inches) at three stages in a six-course rotation, in comparison with ploughing to normal depth (6 inches), and its interactions with dung and fertilisers applied before or after ploughing are being investigated in an experiment started in 1944. All stages of the experiment will be established by 1946. (Physics.)

Grazing experiment.—Since 1937 an experiment on nine plots, each of 5 acres, of permanent grassland has been carried out, at the request of the Royal Agricultural Society of England, to assess the residual manurial value of cake fed to cattle. This question has an important bearing on the compensation payable in tenant-right valuations. The productivity of pasture on which cattle have been cake-fed is compared in the following two years with that of pasture receiving fertilisers applied at rates equivalent to the estimated residual value of the cake, as given in Voelcker and Hall's tables, and with that of pasture receiving neither cake nor fertiliser. The productivity is estimated from the maintenance requirements and live-weight increases of stock (cattle and sheep in a fixed ratio) grazing on the plots in the two years after cake-feeding. The results summarised below show that, over a series of years, very similar returns in starch equivalent have been obtained from the cake-feeding and from the assumed fertiliser equivalent of the cake residues :

Live-weight increase lb. per acre	No treatment	Cake-fed	Equivalent fertilisers
1st year after cake-feeding :[1]			
Cattle	196	253	240
Sheep	88	92	93
2nd year after cake-feeding :[2]			
Cattle	210	232	196
Sheep	85	69	82

[1]Mean of 8 seasons. [2]Mean of 6 seasons.

Starch equivalent, cwt. per acre	No treatment	Cake-fed	Equivalent fertilisers
1st year after cake-feeding[1] ..	13·9	15·8	16·0
2nd year after cake-feeding[2] ..	14·4	14·9	14·6
Increase in two years over no treatment		+2·4	+2·3

[1]Mean of 8 seasons. [2]Mean of 6 seasons.

No clear evidence has been obtained of any build-up in fertility due to the heavier stocking possible on the plots where cake is fed.

Annual experiments

Manurial value of bulky organic manures (1940 *to* 1945).—In each season experimental batches of farmyard manure were prepared from known amounts of feeding stuffs with different proportions of straw as litter. The earlier experiments included tests of the effect of storing the manures, and the later ones compared manures made in covered yards with those made in open yards of baled straw. A wide range of other materials was also included in annual tests on potatoes followed by barley, the potato plots being split to measure the responses to nitrogen, phosphate and potash fertilisers, in the presence and absence of the organic manures. In general there were only small differences between farmyard manures prepared with different amounts of straw. Good results were obtained from long, partially rotted manures. A large part of the merit of the farmyard manures in these tests must be ascribed to the potash they supplied, for whereas in the absence of farmyard manure dressings of muriate of potash increased the crop by several tons per acre, they had but little effect where the needs of the crop had been met by the potash in the farmyard manure. Open-yard manures which had been left exposed to rain for many months naturally lost potash and were somewhat less effective unless a potash fertiliser was given.

Excellent results were obtained in these experiments from bracken cut green in July and stacked until the potatoes were to be planted. Sewage sludges behaved essentially as sources of available nitrogen and phosphate, but not of potash. Town refuses had only small effects. Composts of straw and sewage sludge gave fairly promising results. (Chemistry.)

Experiments on *phosphate fertilisers, fertiliser placement, manuring of sugar beet* and *manuring of flax* formed parts of co-ordinated series carried out in different parts of the country. (Chemistry.)

Winter beans.—Beans are one of the few protein-rich feeding stuffs which can be produced on the farm, and therefore became of increased importance when the importation of feeding stuffs was greatly reduced during the war. Unfortunately, beans are an uncertain crop, and it has been suggested that in recent times the productivity of the crop has declined. One reason for disappointing results is the susceptibility of beans to aphis attack: another reason, shown by the Survey of Fertiliser Practice, is that many farmers are not aware that beans require a liberal supply of potash. Fertiliser experiments in 1939 and 1945 confirmed earlier work in showing that beans respond well to potash. Farmyard manure also gave good returns, probably because of the potash which it supplies. The response to superphosphate was smaller, and nitrogenous fertilisers had little effect.

Experiments on winter beans in 1944 and 1945 showed the importance of early sowing on this soil. Beans sown by drill were severely damaged by birds during germination, but this was avoided if the seeds were sown at a greater depth by ploughing them in. Broadcasting the seed before ploughing, compared with sowing it in rows at the bottom of the ploughing furrow at varied spacing but the same rate per acre, had little effect on yield.

Kok-saghyz and krim-saghyz (*Russian rubber plants*).—Kok-saghyz is a species of dandelion, one of several which are grown in Russia for the production of rubber. When the loss of Malaya made it imperative to seek other sources of supply of rubber, the Royal Botanic Gardens, Kew arranged for trials at a number of centres to see whether kok-saghyz is a suitable crop for British conditions. An autumn sowing at Rothamsted in 1942 germinated well, but the plants were killed during the winter. The crop was resown in spring but grew very slowly, and much labour was spent on hoeing to control annual weeds. The yield of roots in September, 1943 was only 8 cwt. per acre, and in November 10 cwt., much below yields recorded in Russia, though the rubber content was satisfactory. Fertilisers had no detectable effect on yield, but sulphate of ammonia reduced plant number.

Another rubber-producing dandelion, krim-saghyz, was also tested. An autumn sowing failed, but a spring sowing gave a slightly higher yield of roots than kok-saghyz.

The cropping of newly-ploughed grassland.—Experiments on the cropping of land ploughed out of old grass, in relation to wireworm attack, were carried out in 1939-42. In the first year of each experiment, a variety of crops was grown, followed in the second year by uniform cropping with wheat or oats to compare the residual effects of the first year's crops. The yields of all crops were good and serious damage by wireworm occurred in only one experiment. Here the wireworm population was lower, and the yield of spring oats greater, after beans than after other crops. (Entomology.)

Eyespot disease of wheat.—The effect of "eyespot" disease, caused by infection with *Cercosporella herpotrichoides*, on wheat was investigated during the years 1941-1945. The loss of yield caused by the disease was measured by varying experimentally the intensity of infection. Varietal differences in susceptibility to infection and to lodging, and the effect of application of nitrogenous fertiliser at varying rates and times on the degree of infection and of lodging were studied. Spraying with sulphuric acid provides partial control of the disease, and experiments were made to determine the optimal time of spraying. (Plant Pathology.)

The effect of time of planting on the yield of potatoes, and on the spread of virus disease.—In a series of experiments carried out at a number of centres in the years 1940 to 1943[1] the yield of potatoes was found to be closely correlated with date of planting: one day's delay in planting apparently reduced the yield by over 3 cwt. per acre. An experiment was, therefore, made in 1945 to determine the effect of date of planting, within the period March to June, on the yield obtained from chitted and unchitted seed tubers. Stock seed was used, and tubers infected with leaf roll or with severe mosaic were introduced into each plot, to provide data on

[1] P. H. Gregory, J.Min.Agric., 1944, 50, 557-9.

the rate of spread of virus disease in relation to time of planting. (Plant Pathology.)

Cultivation experiments.—An experiment on a three-course rotation, started in 1934 to compare different methods of preparing a seed-bed, by ploughing, rotary cultivation or tine cultivation, to the normal ploughing depth or to a shallower depth, was discontinued after 1939. A new long-period experiment on the effect of deep ploughing was begun in 1944 (see above). During the intervening years the effect of varied intensity of cultivation, and its interaction with the level of fertility, on the yield of potatoes and of sugar beet, was investigated in a series of one-year experiments. (Physics.)

The effect of war gases on agricultural crops.—Experiments on the effect of spraying with mustard gas or lewisite on a variety of crops, and on the utilisation of the produce of contaminated crops, were made in 1940 and 1941. (Crop Physiology.)

THE FARM

By J. R. Moffatt

General policy

In 1939 the acreage farmed was 420 acres, of which only 138 acres were under arable crops. Much of the grassland was laid down in the early years of the agricultural depression, 1925-29, though some of it was considerably older. As much of this grassland was not very productive and economic conditions were improving, the system of alternate husbandry or ley farming was introduced early in 1939. The intention was to grow two or three arable crops and cash the residues of the feeding stuffs fed on the land before sowing down to long-term leys. The advent of war greatly stimulated this breaking-up policy, but owing to the urgent need for food production most of the land was retained for arable crops for several years.

In 1943 when the drive for food was at its highest the area farmed was 489 acres, the increase over the 1939 acreage being achieved by renting some extra land and by the reclamation of over 17 acres of derelict woodland. In that year 52 acres of old grassland were broken up and the area under tillage exceeded that of grassland for the first time since 1927. 67 acres of old permanent grassland were retained as these were carrying long-term experiments which had to be continued.

By the end of 1945, 140 acres of old grassland had been ploughed up and 20 acres of derelict woodland had been reclaimed; a further 18 acres of old grassland were scheduled for breaking up early in 1946. The area farmed in 1945 stood at 495 acres, and as a result of reseeding, the area of grassland again was greater than that under tillage.

The following table shows the most important changes which have taken place in the farming system during the six years of war.

	1938-9	1941-2	1942-3	1943-4	1944-5
Total acreage of farm	420½	481¾	489½	494½	495½
Tillage acreage	136½	214½	248¾	248½	224
Temp. ley acreage	1	35	45½	58¾	84½
Arable acreage	137½	249½	294¼	307¼	308½
Grassland ploughed	10	24	60¾	8	—
Land reclaimed	—	3	17½	1	—
Acreage of: Wheat	45	66	115½	94	74½
Barley	20	39	52¾	57	49
Oats	13	29½	15	16	16½
Beans	2½	16½	6	12½	6½
Potatoes	6¾	15½	22½	24¾	26
Sugar beet ..	4½	4	5½	4	3¾
No. of experimental plots ..	1,215	1,619	1,570	1,707	1,722
Man hours worked	22,620	40,902	51,826	45,121	41,140
Wages paid	£1,290	£2,901	£3,798	£3,641	£3,713
Horse hours worked	7,950	9,282	9,595	8,440	7,558
Tractor hours worked	995	3,170	4,520	4,194	4,799
No. of tractors	1	2	3	3	4
Average wheat yield (cwt. per acre)	20.7	20.9	22.6	25.07	25.14
Purchased foods	£473	£187	£39	£73	£110
Nitrogenous fertilisers used (tons)	10	23.25	29.25	44.5	42.75
Value of produce sold	£2,922	£5,303	£5,628	£7,383	£7,401

The most notable changes which have taken place, and which reflect the trend in farming generally, are the big increases in the area under tillage and under temporary leys, which together give a very big increase in the area of arable land. This in 1944 and 1945 amounted to an increase over the pre-war figure of 124 per cent. with the tillage area, when at its maximum in 1942-44, showing an increase of 82 per cent.

The area under wheat and barley increased rapidly until 1943, when they gave an increase of approximately 160 per cent. The acreage of potatoes has shown a rapid increase throughout the whole period, and in 1945 was almost four times the pre-war figure.

The number of experimental field plots has gradually increased and in each of the last two years numbered over 1,700. This increase in experimental work together with the increased area of crops needing a lot of labour almost doubled the number of man hours worked. The sudden rise in 1943 was due largely to the unskilled and less efficient labour which had to be used to harvest the 184 acres of cereals and the roots crops. The combined effect of the greater number of hours worked and the change in agricultural wages, which rose from 35/- to 70/- in the period under review, is seen in an approximately threefold increase in the total amount of wages paid.

The number of horse hours worked remained more or less constant, as most of the extra field work was done by tractors, which increased in number from 1 to 4 over the period. With tractors available, some work, such as corn drilling and harrowing, which was previously done entirely by horse teams, was taken over by tractors. The tractor hours worked show big increases up to 1943, when there were three tractors, but the purchase of a fourth tractor in 1945 resulted in only a small increase in the total number of tractor hours worked. The old one which it replaced was still retained as a reserve and is fully employed at busy periods. It is also useful as a standby should one of the other three break down.

Despite the fact that phosphates and potash were only very rarely used on the cereal crops, and as many as four consecutive corn crops were taken on the same field, the mean yield of wheat per acre has shown a steady increase. This can be attributed mainly to the more liberal use of nitrogenous fertilisers on wheat varieties chosen for their ability to stand up to these heavy dressings.

The total value of the produce sold off the farm rose steadily throughout the period. In 1944 and 1945 it was more than 2½ times that of 1939, and averaged approximately £16 per acre over the effective acreage.

Rotation of crops

No fixed rotation was adhered to. The usual policy adopted was to plough up the old grassland during the winter months when no other land work was possible, and to take spring oats or barley as the first crop. Two, three or even four successive corn crops were taken, depending on the condition of the land, and these were followed by a root crop or a long-term ley. In 1943, some 184 acres, over 70 per cent. of the tillage area, were under corn crops. Root crops were generally confined to the old arable ground in order that

it could be effectively cleaned, and most of the dung went to the potato crop. The bean crop, which had been given up before the war because of the serious losses from bean aphis in bad years, found its way back into the rotation owing to the need for a home-produced, protein-rich food for livestock. The basic rotation on the old arable ground was roots (kale, potatoes or sugar beet), wheat or barley, beans, wheat, oats, but it was not possible to follow it strictly.

Crops and varieties

During the war years the aim was to get the maximum yield combined with reasonable quality, and to this end some modifications were made from pre-war crops and varieties. The most important of these are set out below.

Wheat

Under pre-war conditions the varieties most commonly grown were Squareheads Master and Victor. As neither of these varieties can withstand heavy dressings of nitrogen they were replaced by stiffer-strawed varieties. Desprez 80, Vilmorin 27, Als, Bersée and Jubilégem were all used with success, but Desprez 80, which possesses the stiffest straw, was discarded after two seasons owing to its susceptibility to rust. By the use of these newer varieties yields were considerably increased and average yields of experimental and non-experimental crops in 1944 and 1945 were over 25 cwt. per acre.

Oats

This crop was grown only for feeding to stock on the farm. Spring oats were generally the first crop after newly ploughed grassland, and the variety used was Star, as this proved to be the heaviest yielder on this soil. In order to spread out the harvesting period, winter oats replaced the spring variety in 1944-5 Picton and S147 were grown and both withstood the hard winter of that year. S147 proved the more satisfactory and a further area of this variety was sown for the 1946 harvest.

Potatoes

Before the war most of the small area devoted to this crop was planted with Arran Banner with a small area of Majestic. During the early war years this position was reversed and later Majestic only was grown. The change was made because Majestic yields about as well as Arran Banner and has the big advantage that sprouting does not take place so early in the spring. This makes sorting in the spring very much easier, and this advantage is especially marked when sorting end-of-season reserves in late spring and early summer. Majestic has the further advantage that it is less susceptible to late blight, and the larger tubers are less likely to be hollow in the centre.

Beans

This has always been an unreliable crop because of its susceptibility to damage by bean aphis. With the need for a protein-rich food this crop was grown again, and satisfactory yields were obtained in most years. In 1944 bean aphis considerably reduced

the yield, but there was some evidence to show that damage by the aphis was not so severe where farmyard manure or potash were given. No new varieties of beans have been introduced, but several different strains are now being tested and grown.

Linseed

This crop was re-introduced in 1944. The La Plata variety formerly grown, gave a poor yield of seed from a bushy plant, difficult to harvest with a binder. This was replaced by the variety Royal which gives a higher yield of seed on a taller and less bushy plant, and the capsules are less susceptible to damage by birds. The crop is either used for stock feed, sold for seed, or for the extraction of oil.

Sunflowers

This rather uncommon crop was grown on small areas in 1943 and 1944, as the high prices offered for the seed made this seem a profitable crop, providing no difficulties were encountered in its cultivation and harvesting. The crop presented no difficulties, if sufficient labour was available at harvest time, and arrangements were made for the proper threshing and immediate drying of the seed. In 1945 nine acres were devoted to the crop, and although the season was unfavourable and resulted in low yields, a satisfactory return was obtained.

MANURES AND MANURING

No phosphate or potash fertilisers are used on commercial crops, except on fields which are unsuitable for experimentation, to avoid building up reserves of phosphate and potash in the soil that would interfere with subsequent field experiments on the use of fertilisers. Consequently, the rationing of fertilisers had very little effect. The full allocation was taken each year, but by the end of the 1945 harvest sufficient reserves had been built up to serve the 1945-46 crops without drawing any allocation for that year. The potash allocation was reserved exclusively for the potato, sugar-beet and bean crops, while few of the corn crops received phosphates. Large quantities of nitrogenous manures were used, mainly as sulphate of ammonia. This was in plentiful supply most years, and only in 1943 was any difficulty encountered in obtaining supplies. Over 40 tons were used each year since 1943, sufficient for an average dressing of over 1½ cwt. per acre including grassland. Very few crops were grown which did not receive nitrogen. Varieties were chosen mainly for their ability to stand up to and respond to these heavy dressings, and there is no doubt that the policy was well suited to wartime conditions.

LIMING AND CHALKING

The lime status of most of the permanent arable fields and the fields which were laid down to permanent grass about 1928 was fairly satisfactory although rather uneven. This was the result of very heavy dressings of chalk applied in the days of Lawes and Gilbert, when dressings of 50 tons per acre were common. The

chalk was dug from small pits in fields where it was fairly near the surface. It was only the old permanent grass and the reclaimed woodland which were really acid. To most of this old grassland, small chalk was applied direct from lorries at 10 tons per acre (the minimum dressing which could be spread satisfactorily), while some of the very acid woodland was given over 20 tons per acre. Grass and woodland not sufficiently acid to warrant such heavy dressings were given ground chalk at 10 cwt. to 2 tons per acre according to their requirements. A small amount of ground burnt lime was used to even out irregularities in the arable fields.

Most of the chalking programme was carried out in 1942 when the grant towards the cost of this work was raised to 75 per cent., and in that year 102 acres were treated with 1,021 tons of lime or chalk. During the 6 years 1940-45 a total of 955 tons of small chalk, 157 tons of ground chalk and 32 tons of ground burnt lime were used on 212 acres of land.

Straw disposal

This problem became acute in 1943-44 after the harvest of 1943 when there were 184 acres of corn, with much old straw still in the stack. Supplies of hay were short and the high prices precluded buying-in. So from that time onward all barley straw as well as oat straw was fed to stock, either in yards or in the fields. In order to convert as much wheat straw as possible into farmyard manure, store stock were yarded during the winter months. They were fed almost entirely on oat and barley straw with a small protein-rich supplementary ration of concentrates, and a small allowance of discard potatoes or kale. Much larger quantities of straw than usual were used for litter and its decomposition was accelerated by the addition of sulphate of ammonia to the yards. As the yards were covered there was not sufficient moisture to wet the straw and water was pumped on periodically, but care was exercised to see that no drainage took place from the yard. The resulting dung-compost was used fresh in the spring in the potato bouts, and though in appearance it was longer and more yellow than the ordinary dung it produced very satisfactory results.

Cattle were given free access to the wheat-straw stacks in the fields during the autumn and early winter. A large proportion of the straw was consumed and the remainder which was pulled out and trodden under by the cattle, was made into compost where it lay by the addition of sulphate of ammonia and water pumped from nearby water troughs. This again was used to good effect on the potato crop.

The chaff and cavings from threshing, which could not be burnt because of blackout restrictions, were all utilised, the wheat chaff and barley and oat cavings as stock feed, and the remainder was made into compost. Some of the older wheat straw was also made directly into compost either with sulphate of ammonia and water, or with sewage sludge and water.

None of the compost heaps were turned as the labour was not available, but the results of the first two seasons showed that if plenty of water is used the heaps rot down satisfactorily except

for a little on the outside. The dry material from the outside was not used, but formed the base of the next heap. Normally the temperature rose to over 70° C. within a few days and on one occasion a temperature of 95° C. was recorded.

Feeding stuffs

At the outbreak of war there was a good stock of feeding stuffs in hand and these were carefully husbanded. In 1941 when the allocation of feeding stuffs depended upon the sales of corn, our allocation was so high that we were asked not to take the full amount. Since then only very small allocations have been made and the farm has been almost self-supporting. The sugar-beet pulp allocation from the beet factory was a very welcome addition. When buying feeding stuffs those containing the highest proportion of protein were purchased, and these with the home-grown beans enabled the livestock rations to be correctly balanced.

Implements

Until about 1939 many of the implements on the farm were old and nearly worn out, and many of them were horse machines which had been adapted to tractor haulage. In that year a start was made to replace the older machines by new ones. The outbreak of war greatly accelerated this programme, and now there is an excellent range of modern implements. Field work has not been hindered by lack of implements although on a few occasions implements were hired from the War Agricultural Executive Committee. The number of tractors was steadily increased from one in 1939 to four in 1945 to keep pace with the cropping programme. All tractors are of the four-wheeled type and two of them are row-crop machines to which toolbars can be fitted. Items of new field equipment were a set of heavy disc harrows, a combined seed-and-fertiliser drill, a crop-spraying machine capable of dealing with sulphuric acid, and an elevator-type potato digger.

Labour

As on other farms the biggest difficulty experienced during the war years was the shortage of labour. This was accentuated by the shortage of cottages on the farm, and even had skilled workers been available there was no accommodation for them. In 1941 and 1942 help was given by young local workers and members of the Women's Emergency Land Corps, but after 1942 these sources of labour almost dried up, and in 1942 and 1943 help for root singling and potato picking was given by local youth organisations and by school children. The arrival of Italian prisoners of war in 1943 considerably eased the position and a team of four has been engaged continuously since then. For urgent seasonal work larger gangs of Italians were used, and were subsequently replaced by gangs of German prisoners.

Buildings

In 1939 the farmstead consisted of an assortment of buildings, some quite new while others consisted of army huts and hangars used in the 1914-18 war. The older buildings were ill adapted for

present-day requirements and were inconvenient besides being worn out. A building programme was inaugurated in 1939, but instead of the gradual replacement of the old buildings which was intended, the programme was pushed ahead with all speed after the outbreak of war. We were fortunate to get all the essential buildings erected and fitted out by the time building restrictions were imposed. They included a range of implement sheds and tractor garages, a service block including cloakrooms and a mess-house for the men, two cedarwood cattle yards, a granary with feeding-stuffs loft over it, and a food-mixing room, and further covered barns and covered threshing gangways to facilitate the storing and threshing of experimental crops. Some of the older buildings were adapted for other purposes, a new surface-water drainage system was laid, and the roads round the buildings were made up.

The main buildings now form a compact block, rectangular in shape and under a continuous roof, so that it is possible to get to almost any part of the buildings dryshod.

The buildings were designed to allow as much productive work as possible under cover during the winter months, to provide the best facilities for this work, and to make working conditions as good as possible. They were wired for electric light and power, and many labour-saving devices were incorporated.

Use of electricity

Electric light and power was supplied to the farm in 1932, and in that year many operations previously performed by internal-combustion engines were adapted for electrical drive. However, the full advantage of electrification is only secured if each machine to be driven is fitted with its own motor of the correct type, and the self-contained unit is placed in the most convenient position for the operation. The proper placement of farmstead machinery is vitally important and can seldom be achieved if the machines are driven from a countershaft, with its attendant transmission losses. The placing of the farmstead machinery in the new buildings was planned before the buildings were erected so that a very convenient layout was assured. The unit-drive principle was adopted wherever possible, and although this was more costly in the first place there is no doubt that it will soon repay the extra cost. The electrical equipment has been increased during the past six years, and now consists of twelve motors ranging from a 20 h.p. motor used for driving the large threshing machine down to a $\frac{1}{2}$ h.p. portable motor which is used for work previously carried out by hand, e.g., potato sorting, winnowing, seed dressing, and tool sharpening. The absence of noise and fumes, the ease of starting, the small amount of attention required by the motors, and the reduction of the risk of fire make electricity the ideal form of power in the farmstead.

The most important new items of electrically-driven farmstead machinery that have been installed are the Essex automatic hammer mill for grain grinding, the food-mixing machine, the hoist with swinging jib for loading and unloading vehicles, and the air compressor used for controlling pests of stored products and for inflating pneumatic tyres. A pneumatic grain conveyor will, it is hoped, be installed shortly.

STORAGE OF POTATOES UNDER COVER

There are many advantages to be gained by storing potatoes under cover instead of in outside clamps: earthing-up is avoided, profitable inside winter work is provided irrespective of weather conditions, the sorting operation is made more congenial, and with the aid of electric light the work can be carried on throughout the whole day in winter, and the unpacking and packing up at the start and end of the day is eliminated. The main drawback to this method of storing is that if the potatoes can only be stored to a depth of about 4 feet, a large area of roof space is needed though much of the covered space is not utilised.

In 1943 a trial was carried out to test the effect of storing potatoes in a much larger heap than is usually recommended. The heap, measuring 40 feet by 11 feet wide by 6 feet deep, was made under a Dutch barn with the retaining wall on the open side made of straw bales, while on the closed side bundles of straw were placed against the corrugated iron. Majestic tubers, which were blight free, were carted straight from the field in late September and after a few days were covered with straw. The bulb of a recording thermograph was placed in the middle of the heap a few days later to record temperatures. Although a considerable amount of sweating took place no rise in temperature was recorded. The heap was opened at the end of January, 1944, and the potatoes came out in perfect condition.

In 1944 the trial was repeated on the same site but with the heap 7 feet deep. The thermograph was installed immediately the heap was completed and on this occasion an initial rise in temperature of 2·6° C. was recorded. During the very cold spell in December, 1944 and January, 1945 the temperature in the heap remained below freezing point for four weeks, but when the heap was opened at the end of January, 1945 the potatoes showed no evidence of injury.

In 1945 a further trial was carried out on a heap measuring 21 feet by 24 feet with a height of 9 feet against the straw-bale walls sloping up rapidly to 12 feet, and containing approximately 100 tons of potatoes on a floor space of 56 square yards. Again there was an initial rise in temperature of 4·7° C. followed by a steady fall, and the potatoes were in perfect condition when sorted in March and April, 1946.

These trials have shown quite conclusively that Majestic tubers which are free from blight and reasonably dry when lifted can be safely stored under cover in very large heaps without any deterioration taking place.

THE USE OF HERBICIDES

Weed control became a serious problem owing to the shortage of labour and as a result of taking several successive corn crops. Sulphuric acid and copper sulphate had been used in past years on the non-experimental fields with some success, but the former can only be used on cereal crops and the latter is efficacious only against certain weeds. In 1944, in conjunction with the Botany Department, preliminary tests were made with dinitro-ortho-cresol

(D.N.O.C.) and some of its salts. Large-scale tests were made to compare them with sulphuric acid and copper sulphate plus salt against weeds, particularly charlock in barley. Small-scale tests were made to ascertain what crops could withstand spraying with these materials.

The large-scale tests showed that the D.N.C.O. and its compounds gave a very good kill of charlock at all stages of growth, and had very little effect on the barley, even if the spraying was delayed until the end of May when the charlock was in full flower. Sulphuric acid used when the plants were young, gave a much quicker and equally good kill of charlock, but the barley was severely damaged, although it grew away well and at harvest time the sprayed area was indistinguishable from the rest of the field.

In the small-scale tests sugar beet seedlings were killed by the sprays, while beans and kale suffered very severely and did not recover. Flax was killed off by all materials except copper sulphate plus salt and the sodium salt of D.N.O.C., and even these two materials caused such a severe setback that plant and yield were greatly reduced.

In 1945 large-scale tests were carried out using an increased range of materials on a wheat crop containing a greater variety of weeds. Very satisfactory weed kills were obtained with "Denoc," D.N.O.C., and the sodium salt of D.N.O.C. plus an activator (sulphate of ammonia), and the only effect on the wheat crops was a slight discolouration of the tips of the leaves. Other materials gave less satisfactory results, but the tests will be repeated.

By the use of these materials a very good control of weeds in cereals was secured. Even perennial weeds such as thistles and docks were so damaged and weakened that they could not cause much damage to the crop by competition and did not recover in time to set seed.

Segmented sugar-beet seed

In 1944 observation plots were laid out to compare segmented sugar-beet seed drilled at 10 lb. per acre with normal seed at 20 lb. per acre. The plants from the normal seed were much thicker in the row before thinning and averaged 58 plants per 100-inch length, compared with 31 plants from the segmented seed. Using normal seed, out of 100 separate inch lengths 32 contained plants, of which 50 per cent. were single plants, while from segmented seed only 22 of the 100 separate inch lengths contained plants, but of these 73 per cent. were single plants. Singling of the plants from segmented seed was noticeably more easy and rapid, and the plant was less damaged, but the final count per acre showed a difference of 4,000 plants per acre in favour of the normal seed.

In 1945 normal seed sown at 16 lb. per acre was compared with segmented seed sown at 4, 7 and 10 lb. per acre. Seed-bed conditions were not particularly good and a spell of very unfavourable weather immediately followed the drilling. The segmented seed germinated much more slowly and unevenly than the normal seed, and when the plots of normal seed were ready for the first horse hoeing those of the segmented seed had to be missed as the rows were not showing sufficiently clearly. These plots remained backward throughout

the season, and the plant number and yield was increased with the rate of drilling. Normal seed gave 5,000 plants per acre more than segmented seed sown at the heaviest rate. This result confirms experience gained elsewhere that segmented seed is not likely to be successful where conditions at sowing time are unfavourable. It also appears that for the lower seed rates to be successful the seed must be placed for more accurately in the row.

Reclamation of derelict woodland

When the estate was purchased in 1934 the growing timber in the woodland was not bought. The vendors felled it in 1938 and left an area of approximately 74 acres of derelict land full of tree stumps, smashed coppice and the rotting trunks of trees which had blown down over the previous ten years. For a year or two nothing was done, but the herbaceous vegetation began to spread with alarming rapidity; it consisted mainly of St. John's wort, willow-herb, burdock, ground ivy, brambles, and some bracken.

It was realised that the area presented problems which would arise in many instances after the war, namely, what to do with small areas of derelict woodland from which all the saleable timber had been removed. Clearing and replanting is costly, and natural regeneration uncertain, and not worth the risk. Furthermore, as small areas of woodland would not warrant the employment of a forester, the plantations would receive little attention and the value of the timber would thereby be reduced. In past years many of these small areas of woodland were planted because the soil was poor and the art of pasture-making was not properly understood. With modern knowledge of soil improvement and pasture-making, and with modern equipment, much of this type of land could be made successfully into pasture or arable land.

The problem of reclamation of this land was tackled in five different ways;

1. *Clearing the surface and direct seeding.* An area of 3½ acres was cleared of surface weeds and rubbish in 1939, everything, including the coppice, being cleared down to ground level. Basic slag was then applied by hand at 10 cwt. per acre, and a mixture of grass and clover seed was hand-broadcast in the spring of 1940. No implements at all could be used because of the tree stumps, and the seeds were not harrowed in. The summer of 1940 was very dry and germination of the seeds was slow, but by the autumn quite a good cover of grass was obtained. No clover germinated that year, but in the spring of 1941 a considerable number of wild white clover plants were found, and since then a good plant of wild white clover has established itself. Some elders, brambles, and thistles continued to grow. The elders were kept in check by cattle eating the young shoots, but thistles and brambles had to be cut by hand in 1940 and 1941. Since then the weeds have caused very little trouble and the area is now carrying a very productive sward of grass.

The ease with which this land was reclaimed, and our subsequent experience with other areas showed that clearing and reseeding should be done as soon as possible after felling, before elders and herbaceous weeds can get established.

2. *Clearing and ploughing before direct reseeding.* The area tackled by this method was 10 acres in size, and had carried a fine larch and spruce plantation. On old maps it was called Clayeroft, probably because of the nature of the soil, and this was probably the reason it was planted to trees some 40-50 years ago. The clearing was not begun until the late winter of 1942, by which time the area was a mass of thistles, burdocks, nettles and willowherb, and direct seeding was impossible. The old wood and the dead tops of the weeds were collected and burnt, although we found out later that these dead weed tops need not have been touched. The ground was then ploughed with a Shearer stump-jump disc plough. The independently mounted discs rode over the top of the stumps, compressing large springs which immediately forced back the discs once the obstacle was surmounted. The plough did very good work and the land was ploughed in both directions. Throughout the summer this area was fallowed and worked with a heavy set of Shearer stump-jump disc harrows. These also did fine work, and enabled the land to be cleared of weeds, besides producing a fine tilth from the heavy soil. The area was slagged and limed during the summer, and a grass and clover seeds mixture was sown in the spring of 1943. These seeds were roughly harrowed in with a set of chain-link harrows. They germinated and grew well, and the field was stocked in July of the same year. It is now carrying a fine sward of productive grass. The larch and spruce stumps, of which there are several thousand, have rotted considerably, and will probably be turned out by a gyrotiller in a year or two when the grass is due to be broken up.

3. *The use of pigs for removing the herbaceous vegetation.* Tamworth pigs were chosen for this work as they are very hardy, and are best able to fend for themselves, while their long snouts are evidence of their ability to root well. The area allotted to them was enclosed by an electric fence, which was very satisfactory once the pigs had learnt to respect it. Our experience showed that pigs can play a very useful part in woodland reclamation, and that for about 7 months of the year they can live on what they find without any supplementary feeding. It is important that they should be given only a small area at a time and should be moved to another areas as soon as the first has been cleared of vegetation and well rooted up. If they are left too long on any one area they will tend to poach the ground badly in wet weather. The pigs are also assured of a more regular supply of food by this system. Bad patches of brambles, which they are not keen to eat except the fruit, should be cut out by hand. The area should be levelled, manured if necessary, and sown with grass seed as soon as possible after the pigs have been removed. This gives the grass and clover seeds time to establish themselves before there is much competition from weeds, for weed seeds establish themselves very quickly in the fine soil turned up by the pigs. The ideal arrangement would be to have sufficient pigs to clear the surface vegetation and root up whatever area can be cleared of coppice, levelled, and manured by the following spring, ready for the seeds mixture to be sown early.

4. *Conversion to arable land.* This method necessitated the

removal of tree stumps and roots from the ground. At first, blasting was tried alone, using polar ammonium gelignite. This was quite satisfactory when dealing with old stumps, which were often lifted out bodily, but was much less satisfactory with the stumps of recently felled trees. The operation usually shattered the stump, but it was then frequently a long and tedious job to remove the sections, which were often firmly held by the roots. However, several acres were cleared in this way. Later, a bulldozer was tried, but although the stumps were removed satisfactorily, this took too long. The most successful method was a combination of blasting and bulldozing. The latter cleared the soil from around the stump to a depth of 1 to 2 feet, the stump was then shattered by blasting, and the bulldozer completed the work by removing the shattered stump and levelling off the ground. About 6 acres were cleared in this way, and although it was expensive, once the operation was completed the ground could be worked by any implement and prepared for any crop.

5. *Re-afforestation.* It was decided to replant 14 acres of the old woodland and to leave 2 acres for natural regeneration, although it was doubtful whether this latter would be successful. A firm of forestry contractors was engaged in 1940-41 to execute the work of clearing and preparing the ground, fencing against rabbits, and planting with ash, oak, and beech according to the nature of the soil. The total cost per acre was approximately £27, and towards this the government grant of £3 10s. 0d. per acre was secured.

Owing to the difficult labour position it has not been possible to keep down the weeds or cut off the shoots from the old rootstocks as often as was required. A four years' growth of weeds and shoots has now been removed, and fortunately the mortality of the young trees is very low, and rapid growth should now take place.

Livestock

Cattle. The cattle policy was governed by the necessity of producing an even bunch of young stock of known history for grazing experiments. Owing to the difficulty of obtaining suitable calves to rear intensively on a few cows, a herd of Blue-grey (white Shorthorn by Galloway) cows and Kerry cows was run with an Aberdeen-Angus bull. They calved outside and reared their own calves, which were weaned into covered yards in the early winter. In the first few years the cows remained outside all the year, but when the problem of straw disposal became acute they were brought into covered yards in winter to tread wheat straw into dung, and to consume the barley straw. The oat straw was mainly reserved for younger stock. A small ration of protein-rich concentrated foods, together with a small allowance of kale or potatoes was also fed. These cows were bulled in 1945 for the last time, as they are now 9-10 years old, and will be sold fat as opportunity occurs.

Sheep. The grass flock of Half-bred (Border Leicester × Cheviot) ewes was retained, although reduced in size, for the production of fat lambs. In order to get lambs as big as possible, Oxford rams were used after 1942, and to economise in feeding stuffs the lambing date was made about three weeks later, so that young

grass would be available for the ewes and lambs soon after lambing. The use of purchased feeding stuffs was almost eliminated.

Pigs. The pig herd was dispersed in 1939 owing to unsatisfactory housing conditions, and because they were no longer required to dispose of the products of the farm. It is unlikely that the herd will be restarted unless pigs prove to be necessary for the general economy of the farm, or are required for comparing the feeding values of produce from experimental plots.

Future policy

The farming system outlined was developed to meet the requirements of wartime conditions, and proved suitable for those conditions. Now that the war is over the system will be modified gradually to meet changing circumstances. Certain modifications have already been introduced, and others will follow ; the acreage of cereal crops has been reduced, and varieties of crops are again being chosen with equal emphasis on yield and quality : the number of cereal crops grown in succession will be reduced and some of the special crops will not be grown again : the disposal of straw will not be such an acute problem and the amount of compost made will gradually be reduced : the same emphasis will be laid on making the farm as self-supporting as possible in feeding stuffs : the livestock population will be increased to make full use of the increased area of temporary grass : the farm buildings and implements will be kept up to date, and farm cottages will be provided so that all the workers needed on the farm can be comfortably housed.

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By J. R. Moffatt

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WOBURN EXPERIMENTAL STATION

By H. H. Mann

The Woburn Experimental Station was originally established in 1876 for two purposes. The first was to investigate the residual value of manures, especially of farmyard manure, and to determine whether this residual value was in any way connected with the composition of the food from which the manure was made. The second was to ascertain whether the results obtained with the continuous growth of corn crops on the heavy lime-rich soils of Rothamsted would likewise be obtained on the light, somewhat sandy, lime-free soils of the Lower Greensand at Woburn. Though these two matters remained for many years the main business of the Woburn Station, yet the scope of the experimental work has gradually been widened, and it now includes the study of all questions which have to do with the maintenance of fertility in light soils in the drier half of England, as well as with the conversion of rather poor soils of this type into high-class market-garden land. The original work was summarised in a volume issued in 1936.*

Seasons

The first three years (1939-41) were wet ones, with total rainfalls of 29·89, 27·60, and 25·52 inches respectively. Each of these years had not only a high winter rainfall (October to February), but also a high spring precipitation (March to June). The second three years (1942-44), on the other hand, were dry ones with rainfalls of 19·49, 19·09, and 22·33 respectively. The mean annual rainfall for the whole period was 23·99 inches, which is very close to the normal for Woburn, namely 24·22 inches. The winter precipitation for this second period of three years was 5·59 inches and the spring rainfall 2·75 inches less than in the first three years of the period. A greater contrast could hardly be imagined for two successive three-year periods.

In other matters the years were quite normal. The mean annual sunshine amounted to 1,497 hours as against a normal of 1,447 hours. The extreme temperatures reached were Maximum 88° F. in June 1941 ; Minimum 4° F. in January, 1942.

Staff

The Woburn Station has been fortunate in that there have been no changes in the staff during the whole of the war period, at least among the responsible members. Dr. H. H. Mann has been in charge both of the farm and laboratory, except for a period of about five months in 1940, when he was in Turkey on a special mission. Mr. T. W. Barnes has remained as chemist, and Mr. W. A. McCallum has been in charge of farm operations throughout. Much of the work has been carried on with the help of visiting members of the Rothamsted staff who have organised and assisted in carrying out a large number of field experiments.

* Fifty Years of Field Experiments at the Woburn Experimental Station, by *E. J. Russell and J. A. Voelcker*. (London, 1936.)

FIELD EXPERIMENTS

Continuous wheat and barley experiments.—Of the experiments originally laid out in 1876, the plots where wheat and barley crops were to be grown every year with various amounts of nitrogenous and mineral manures or with farmyard manure have continued to be under these crops, except that in both cases fallows were taken in 1927-28 and in 1933-34 in order to get rid of the weeds which were threatening to smother the corn crops. After the first of these fallow periods, it was decided to grow the crops without any further manuring for five years to see how far the previous manuring would affect the beneficial result of the fallow. After the second fallow, a further period of five years without manure was taken again, so that we had obtained by 1940 a very clear indication of the result of fallowing on exhausted land which had been differently manured for many years previously. The results obtained during this period were published in 1944 (1). But the enormous benefit of fallowing in giving a largely increased crop even in land which had had no manure of any sort since 1876 was very striking, and amounted to an increase of 50 per cent. in the wheat and 140 per cent. in the barley crop. This benefit soon passed off in succeeding years, and the falling off seemed hardly to be affected by the previous manuring of the land.

After 1940, another phase of the study of these plots was undertaken. How far is the effectiveness of nitrogenous manures affected by the previous manuring of the plots? This matter was taken up in 1943 and is now being investigated, using nitrochalk (a mixture of ammonium nitrate and calcium carbonate) as the nitrogenous manure, applying it in three different doses. By the end of 1946, definite results should have been obtained on both the wheat and barley plots.

It might be well to call attention to the continued sterility of the plots which for the first fifty years of the experiment received sulphate of ammonia without any addition of lime to counteract the acidity which this fertiliser produces. When the further addition of sulphate of ammonia ceased in 1926, it was interesting to see how quickly, if at all, the fertility of these plots recovered. Now, after twenty years, it may be said that there is no evidence of any recovery of fertility, the few weak feeble plants of wheat or barley that grow are purely pathological specimens, and the plots have tended to become the homes of certain grasses notably *Holcus mollis* and *Agrostis stolonifera* which seem to flourish on soil too acid to grow either the crop plants or the normal weed herbage of the soil.

The maintenance of the fertility of light sand.—With the increasing difficulty of obtaining farmyard manure, the question of how best to maintain the fertility of such land as that at Woburn becomes of greater and greater importance, and hence the chief work of the Woburn Station has tended to become the investigation of various methods of obtaining the result. Some authorities have maintained that if a suitable rotation be followed the fertility can be maintained by the use of artificial manures alone. Others have recommended the use of a system of alternate husbandry, thus combining a periodic ley with arable cropping. Others again have laid stress on the value of green manures for this

purpose. All these methods have been and are under study at the Woburn Station.

(a) *Rotation experiment with artificial manures only.*—This experiment has been carried on since 1930, using no outside organic manures, but applying various amounts of sulphate of ammonia, superphosphate and muriate of potash to each crop. The rotation used consists of barley, clover, wheat, potatoes, rye and sugar beet. The results have not been worked up in detail, but one or two are clear. There has been so far no sign of any general deterioration of the crops as a result of using artificial manures alone, and the crops of barley and rye, at least, continue to be among the best on the farm. On the Woburn soil, the effect of phosphates and potash manures has been very small, hardly significant, in fact, while the chief agent in maintaining the crops is the nitrogenous manure which gives a significant increase almost every year in all the crops except the clover.

(b) *Alternate-husbandry experiment.*—This experiment, laid out in 1938, has for its object to compare the fertility of soil after three years under a grazed grass-and-clover ley, or under lucerne which is annually cropped for hay, with land which bears a well manured arable crop each year. The actual rotations which are compared are as follows :—

(*a*) Three years' ley, grazed ; potatoes ; barley.
(*b*) Three years' lucerne, cut for hay ; potatoes ; barley.
(*c*) Potatoes ; wheat ; one-year seeds cut for hay ; potatoes ; barley.
(*d*) Potatoes ; wheat ; kale ; potatoes ; barley.

It will be seen that the first two of these involve the land being under one undisturbed crop (ley or lucerne) for three years, while the second two are annually cropped and ploughed. The relative fertility of the land after these treatments can be ascertained by the crops of potatoes followed by barley which are then obtained. A similar amount of phosphate and potash manures is given in all cases. One half of each plot received 15 tons of farmyard manure per acre applied to the first testing crop of potatoes, in order to judge whether this is equally effective after the ley or lucerne and after the continuous arable cropping.

In 1944 the experiment had been going on long enough to make it possible to formulate at least two provisional conclusions. The first of these is that the land is more fertile, as judged by a crop of potatoes, after a grass and clover ley grazed or after a three-years' lucerne crop hayed each year, than after either of the two continuous arable rotations, the difference amounting to about 2 tons of potatoes per acre on a 14-ton crop. In the second year, when barley is grown, the difference apparently disappears. The effectiveness of the added dressing of farmyard manure to the potato crop after the grazed grass-and-clover ley is far less than after either the lucerne ley or the continuous arable crops.

(c) *Green-manuring experiment.*—The use of green manures for the maintenance of land fertility has often been recommended and experiments on the subject, using mustard and tares as green manures, have been carried on at Woburn ever since 1893. The present experiment, laid down in 1936, compares the effect of mustard and tares grown in spring, rye grass and clover sown in a pre-

vious crop of barley, and a mere fallow, all being ploughed-in about June, on a following crop of kale succeeded by a crop of barley. The technical difficulties of such an experiment are great, and the kale crop has several times failed when put in as soon as is possible with the above scheme. But taking those years only in which the kale and the barley crops were a success, the following results seem clear. The annual green manures mustard and tares have not raised the crop of kale above that on the fallow plots, and while clover has given an increase of 1·67 tons per acre (22 per cent.), the burial of the rye grass has caused a reduction in yield of 1·98 tons per acre (27 per cent.). In the crop of barley which follows the kale, the difference which can be ascribed to the green manures is very slight, except in the crop following clover where about 1½ bushels of barley extra was on the average obtained per acre. On the whole, it may be said that we have not been able to devise a method of using green manures effectively so far, and the experiment is now being modified to try other methods of applying them.

The making of a market-garden soil.—The usual method of converting an ordinary field soil into the condition which allows the successful cultivation of market-garden crops has been to dress the ground heavily with farmyard manure and then maintain its fertility by dressings both of organic materials, like shoddy and soot, and artificial manures. With the increasing difficulty of getting farmyard manure, it is important to find some substitute for this, and an experiment was devised in 1942 to see how far it could be replaced by sewage sludge either alone or as a sewage-sludge compost, or by composts made from the refuse materials of any farm, along with a judicious use of phosphates and potash manures, with or without the additional use of nitrogenous manures such as sulphate of ammonia. The area chosen for the experiment was one which by its general character and texture should make good market-garden soil, though it was in a very exhausted condition. Each of the above organic materials as well as farmyard manure as a control was applied each year at the rates of 15 and 30 tons of material per acre, with a basal dressing of phosphates and potash also, along with plots to which only a nitrogenous dressing of sulphate of ammonia was applied. A two-year rotation of vegetables was adopted, namely, first year—early green peas, followed by leeks, second year—globe beetroot, followed by winter cabbage. The experiment was carried on from 1942 to 1944 with success, but the results are not ready for discussion. It is clear, however, that the area is gradually developing the characteristics of a market-garden soil, and that the utility of the organic manures is coming out very clearly. There seems little difference so far between the farmyard manure, the sewage sludge, and the vegetable compost. The compost made from sewage sludge seems distinctly less effective.

The value of refuse manures.—At the commencement of the war, the need for manures to increase the food and fodder supply was very keenly felt, and this led to many experiments being done with various forms of town refuse, to see whether this could be profitably utilised as a manure. One of these was a proprietary material marketed under the name " Hyganic " manure, and the other a screened town refuse

from Chesterfield. Both were applied to sugar beet in 1940 and the experiment was continued in 1941 with mangolds, to see whether there was any residual effect. Both the materials mentioned were poor in nitrogen, the Hyganic containing 0·59 per cent. and the Chesterfield town refuse 0·40 per cent. of nitrogen. The general results showed that while the farmyard manure produced significant increases in the yield of sugar per acre in the sugar beet, the screened refuse from Chesterfield gave only a small increase and the Hyganic manure a slight depression in yield. There seemed no reason to suppose that even under the stress of war-time conditions, the ordinary screened town refuse, whether treated further or not, was likely to be a manure for sugar beet or mangolds that would be worth carting and spreading on the fields.

Manurial experiments with sugar beet.—In 1939, it was shown that all the usual nitrogenous manures (nitrate of soda, nitrate of lime, sulphate of ammonia and muriate of ammonia) were of nearly equal value at Woburn, sulphate of ammonia giving, on the whole, the lowest yield. Ordinary agricultural salt gave an increase of yield which would repay the cost of application, and other salts of sodium or potassium also gave an effect, though a smaller one. Sulphates seemed to reduce the percentage of tops to roots in sugar beet, at least in 1939.

The manuring of sugar-beet seed.—The growing of sugar-beet seed in Britain is a new thing. Before the recent war, there was no difficulty in importing from Germany and Holland all the seed required. It was only when these sources were no longer open that an organisation grew up for the production of sugar-beet seed in Britain. There has been no investigation of the manurial requirements of the sugar-beet crop, and hence experiments were carried on for two years at Woburn. The results of these have recently been published (2), and indicate that the effect of farmyard manure (10 tons per acre) was variable, but on the whole gave a distinct advantage in the yield of seed, that the yield was greatly increased by sulphate of ammonia and this had no injurious effect on the ripening of the seed, that agricultural salt applied at the rate of 3 cwt. per acre at the time of transplanting the stecklings improved the yields of seed, and that, on the Woburn soil, both superphosphate and muriate of potash were ineffective. These experiments are the only ones carried out in this country on the manuring of sugar-beet seed.

Cultivation experiments with sugar beet.—In conjunction with Drs. B. A. Keen and E. W. Russell, experiments have been made for several years on the effect of intercultivation on both the sugar-beet and the lettuce crops. The results on sugar beet have been published in (3).

The results obtained with lettuce—a crop which is supposed to be peculiarly susceptible to intercultivation—have been similar.

The manuring of carrots.—During the early part of the war, the A.R.C. organised experiments on the manuring of carrots in various parts of the country, and as Woburn is peculiarly suitable for carrots, such experiments were conducted there in 1941 and 1942. These tested all combinations of treatments with varying amounts of nitrogen as sulphate of ammonia, phosphoric-acid as superphosphate, and potash as muriate of potash. In 1941

the roots were planted late and the mean yield was only 5·21 tons of carrots per acre: in 1942 when they were planted in good time as main-crop carrots, the mean yield reached 22·9 tons per acre. The general result here, as in most other centres, was that nitrogenous manures were doubtfully effective, for they gave a significantly increased yield in 1941 with a small crop, but not in 1942 when the crop was a good one: and that salt gave a significant increase in crop. Other manurings were ineffective on the type of soil that is found at Woburn. The results were included in a report by Dr. E. M. Crowther to the A.R.C., but they have so far not been published in detail.

Work with the lucerne crop.—The lucerne crop has always been very successful at Woburn, with its deep soil without a definite water table. The effect of inoculation of the seed even when lucerne had not been grown on the soil previously has been negligible, and an adequate crop of lucerne has been maintained for eight years without resowing, with a mean crop of lucerne hay for eight years of 3·82 tons per acre, of which 61 per cent. was obtained in the first hay crop of the season. In the highest year, the crop of hay was 6·5 tons per acre (4).

On the Woburn soil, a second experiment showed a negligible effect not only of inoculation of the seed, but also of treatment with farmyard manure. Incidentally, this experiment showed that an excellent crop of lucerne could be obtained on soil which was slightly acid, provided the pH value of the soil did not go below 5·8.

Take-all disease experiment with wheat and barley.—Since 1943 an experiment has been undertaken on various methods of field treatment of the land on the take-all disease of wheat and barley. This is being done in co-operation with Dr. S. D. Garrett. It deals with the effect of time and amount of tillage, of the presence or absence of an undersown leguminous crop (trefoil), and of the presence or absence of an active nitrogenous manure like sulphate of ammonia, on the prevalence of the disease among the barley crop. The results appear promising as a means of practically reducing the amount of damage done by the disease.

Special crops.—For a number of years, we have, at Woburn, grown several crops which are relatively new to this country, notably maize grown for seed, and soya beans. We have now got types of both crops which can be relied on to ripen in England, and a demand has arisen for the seed of both of them. The worst feature of either is the fact that the early types which are inevitably grown are dwarf kinds which yield badly, and in recent years the main object has been to see whether by modifications in the method of growing them the yield could be increased to a paying level. Two results are clear in both these crops. First, they can be safely sown earlier than has been thought in the past, and the third week in April seems to be safe for both crops. Second, they should be sown closer together than has been the custom with the full-size crops usually grown in other countries. An account of the present position with regard to the growing of soya beans in England was given in (5).

Pot experiments.—The pot-culture station at Woburn was the first to be established in this country. It was opened in 1898 and was for many years chiefly used in connection with the Hills

experiments on the value of trace elements on various crops. In recent years it has been used for investigations in four different directions. These are as follows ;

1. *The utilisation of nitrogenous manures when added to the soil.*—Work has been carried out at Woburn since 1929 to ascertain the fate of nitrogen added as nitrogenous fertiliser to soil (a) by observing the effect on cereal crops when grown on the land and (b) by the extent to which the nitrogen can be found in the drainage water. A large number of results have been obtained and it is hoped to publish them very soon. An account of the early results was issued in the Journal of the R.A.S.E. by E. M. Crowther and H. H. Mann in 1933. The results indicate that in whatever form a nitrogenous manure is applied to the soil, the nitrogen in it disappears in part from the system over and above that removed by the plants or by drainage ; that the effectiveness of an organic manure not only depends on the percentage of nitrogen which it contains, but also on the length of time it has been in contact with the soil before being utilised. Various other points have been brought out, and the work is still continuing.

2. *Studies in connection with acid soil.*—The fact that on the permanent wheat and barley plots at Woburn the soil has become very acid (the pH value having gone down to about 4·2) has given a chance for a close investigation of the cause of the infertility of such soil and the methods by which it can be remedied. An account of the work done up to 1939 was issued in 1940 (6). It showed that for barley there exists a critical point below which barley will not grow normally, but that the crop can tolerate higher acidity if there is a treatment with large amounts of farmyard manure. Since then the cause of this phenomenon has been under investigation, and the effect of increasing the organic matter in the soil by other means, of increasing the colloid content of the soil by the use of bentonite, and of adding an amount of organic fertilisers containing an equal amount of plant food to that in the farmyard manure has been tested. The work is still going on.

3. *Studies on clover sickness.*—The phenomenon known as clover sickness, that is, the failure of clover on land which has grown the crop for several years, has been studied at Rothamsted ever since its early days. As it is particularly prevalent at Woburn the study was taken up here about ten years ago, and important results which were published in 1939 (7) have been obtained in connection with it. It is now clear that the disease is independent of the eelworm to which it has been attributed, that no fungus seems to be the cause of the affection, and that it can be temporarily got rid of by heating the moist soil to 70° C. for two hours or by treating it with large dressings of farmyard manure. The work is being continued and a further paper on the subject will shortly be issued.

4. *Studies of weeds.*—The weeds growing on the several plots of the wheat and barley experiments in the field were the commencement of this study, and the variation between the herbage found on plots differently manured was described in detail in 1939 (8). Since then the further study has taken the form of an investigation of the competition between barley and certain weeds under controlled conditions. The first two weeds studied in this

connection were the two commonest found in the field at Woburn, namely *Spergula arvensis* and *Matricaria inodora*, and an account of them has been recently published (9). In the last two years, the worst of our " twitches " namely *Holcus mollis*, which is very common and very troublesome on all the Lower Greensand area in which Woburn lies has been considered by similar methods. In this case, we have investigated the competition of barley and the weed when the root space is constant but where the thickness of the barley and also of the weed varies, in all cases in presence of excess of plant food of all kinds. The results will be published in due course.

PUBLICATIONS

1. MANN, H. H. 1943. *The influence of fallowing on the yield of wheat or barley on very exhausted land.* J. Agric. Sci., **33**, 207.

The influence of two years of bare fallow on the fertility of light land exhausted by continuous cropping with wheat or barley for fifty years has been very great, the immediate result being an increase in the crop of wheat by 50 per cent. and of barley by 140 per cent. over the average yield of the unmanured plots for the ten years before the fallow was taken. A repetition of the fallow after a further period of five years of continuous cropping without manure gave a very similar result.

Whatever had been the treatment of the land during the fifty years before the fallowing, the yield produced as a result of the bare fallow fell off very rapidly in the succeeding years when no further manuring was given. Previous manuring either with artificial manures or by farmyard manure affected very little the falling off of the yield, though it was not so complete in the latter case as with the former.

2. MANN, H. H. and BARNES, T. W. 1945. *Manuring for the production of sugar beet seed.* J. Min. Agric., **52**, 400.

The yield of seed when transplanted stecklings of sugar beet are manured with farmyard manure (10 tons per acre) was variable but on the whole gave an increase of 157 lb. per acre. Sulphate of ammonia also gave an increase of 241 lb. seed per acre with a dressing of 2 cwt. of the fertiliser per acre, and there was no sign of delayed ripening of the seed in this case. Superphosphate and muriate of potash had little effect on the quantity or the quality of the seed, but a dressing of agricultural salt (3 cwt. per acre) gave an increase of 173 lb. of seed per acre.

3. RUSSELL, E. W., KEEN, B. A. and MANN, H. H. 1942. *The effect of intertillage on the sugar beet crop.* J. Agric. Sci., **32**, 330.

If the soil nutrients are in short supply hoeing and hand weeding increases the yield of the beet, provided these operations are carried out before or shortly after singling. Hoeing is more effective than hand weeding, but it cannot yet be said with certainty whether this is due entirely to more efficient weed destruction or whether there is some additional effect such as mulching. If adequate quantities of soil nutrients are present, inter-row cultivation has little effect on yield, and the crop can tolerate a considerable weed infestation without any effect on yield.

4. MANN, H. H. 1944. *History of a lucerne crop.* J. Min. Agric., **51**, 32.

Presents the results of an eight year crop of lucerne, at Woburn, which gave a mean yield of 3·82 tons of lucerne hay per annum with a maximum of 6·51 tons in the fourth year. Three crops were usually obtained each year and the amount of nitrogen in each crop and hence its protein value, was very similar. The first crop in each year was usually about twice the weight of the second, and the latter, was about twice the weight of the third. The roots of the crop penetrated to about five feet deep.

5. MANN, H. H. 1941. *Soya bean culture in Great Britain.* Nature, **147**, 660.

Discusses the successful commercial cultivation of soya beans in Britain, and concludes that the summer is not hot enough to give successful results except with some of the dwarf types. These give a relatively small yield. They should be sown between April 15 and May 15 and the suitable types ripen not later than the beginning of October. The future depends on the development of types which will yield more highly or on methods of cultivation which will give more beans per acre.

6. MANN, H. H. and BARNES, T. W. 1940. *Studies of soil after fifty years of wheat and barley cropping, especially of soil made acid with sulphate of ammonia.* J. Agric. Sci., **30**, 345.

This paper discusses (*a*) the composition of aqueous extracts of soils, at Woburn, which have grown wheat or barley for fifty years with various manuring and without such manuring; (*b*) the correction of soils too acid for the growth of barley, and (*c*) the effect of lime on the crops and drainage waters of soils made acid with sulphate of ammonia.

7. MANN, H. H. 1938. *Investigations on clover sickness.* J. Agric. Sci., **28**, 437.

No manuring with lime, phosphates, or potash or with easily available nitrogen has any considerable effect on the capacity of the soil to grow clover. Two methods gave temporary relief. One is to heat the moist soil to 60-70°C. for 1 to 2 hours, but in this case the effect quickly passes off and the soil becomes as virulent as ever. The other method is to give a large dressing of farmyard manure and the length of time during which it is effective varies directly with the amount of farmyard manure added.

The eelworm *Anguillulina dipsaci* seems to have no direct connection with clover sickness and cases have been found where it is not present during an attack.

8. MANN, H. H. 1939. *The weed herbage of a slightly acid arable soil.* J. Ecol., **27**, 89.

This is a study of the weed herbage of the Permanent Wheat and Barley plots, at Woburn. The chief weeds were *Spergula arvensis* and *Matricaria inodora* which were dominant almost all over the area among the annual weeds, and they were accompanied by *Polygonum aviculare*, *Gnaphalium uliginosum*, and *Chenopodium album*, and a few others. One year's fallow does not do much to get rid of these weeds but two years of fallow very largely reduce the annual weeds except *Stellaraia media* and *Poa annua*, which are little affected. Acidity above a certain point causes the disappearance of *Matricaria inodora* and *Vicia hirsuta*, the latter of which was very common on the more highly manured plots.

The perennial weeds which are the biggest trouble are *Holcus mollis*, and *Agrostis stolonifera* which become very serious twitches, particularly on the more acid plots.

9. MANN, H. H. and BARNES, T. W. 1945. *The competition between barley and certain weeds under controlled conditions.* Ann. Appl. Biol., **32**, 15.

The nature of the competition between barley and certain annual weeds which are dominant at Woburn, under conditions where the available root space as well as the water, light, and nitrogen required by the plants are limited, was studied. The weeds involved were *Spergula arvensis* and *Matricaria inodora*. Where there is a limited and fixed root space and where there is a limit to the available nitrogen there is a tendency for the maximum yield of either the barley or weeds, when grown by themselves, to be associated with a certain density of plants. Where extra nitrogen is given a point is reached when the result is to increase the amount of nitrogen in the plants and not the yield at all.

With weeds and barley grown together, increase in the density of the barley plants diminishes the injurious effects of both weeds. The combined weight of the barley and weeds is hardly ever so great as that of the barley grown in weed-free soil.

10. BARNES, T. W. 1945. *Accumulation of sugars in barley seedlings on very acid soil.* Nature, **156**, 692.

When barley is sown on very acid soil, the young seedlings when they are just above the ground are attacked by birds to an extent far in excess of other seedlings grown on more normal soil. This is shown to be due to the accumulation of a much greater amount of sugar in the very acid seedlings.

WAR-TIME FERTILISER POLICY

(Joint Report by the Departments of Statistics and Chemistry)

Before the war the amounts of fertiliser used in the United Kingdom were determined by the price structure and the aggregate demands of individual farmers. Early in the war it became apparent that the amounts of phosphate and potash to be imported would raise acute questions. It would be necessary to use every cubic foot of shipping space to best advantage and this would require a scientific assessment of the total amount of shipping space saved in food imports with different levels of fertiliser imports. For this it was necessary to know as accurately as possible the changes in food production that would result from changing amounts of the different classes of fertiliser or raw material.

Responses to fertilisers

It is a somewhat remarkable fact that no comprehensive summary had previously been made of the results of fertiliser trials conducted in this country. After Dunkirk, it was decided that such a summary should be made as a matter of urgency. The work was carried out with the assistance of various members of other Departments, and a summary of the results of all fertiliser trials in this country since 1900, of which results could be obtained, was communicated in the autumn of 1940 to the Ministries of Agriculture and Supply as a factual basis for a war-time fertiliser policy. As a result of the contacts thus established the administrative and policy-making bodies concerned with fertiliser supplies have worked throughout the war in close association with Rothamsted and a committee of the Conference of Advisory Chemists in considering the scientific and technical problems involved in importing, distributing and using fertilisers.

The summary of experimental results, supported by closely similar ones from other countries in North-West Europe, was published (1) early in 1941 under the title " Fertiliser Policy in War-time," preprints being widely distributed. Subsequently a series of papers was published (2, 3, 4, 5, 6) in agricultural journals to show how the principles of scientific rationing could be applied to practical problems of manuring both during and after the war.

A necessary part of the investigation was to determine the form of the response curves for nitrogen, phosphate and potash in fertilisers or, in other words, to ascertain how on the average the yields varied as the amounts of fertiliser varied. This was required both to estimate the aggregate returns for changing imports and also to standardise results from experiments which had inevitably been carried out at many different rates of dressing. One by-product of the investigation was the demonstration that the response-curve coefficients adopted long ago by E. A. Mitscherlich, though substantially correct for phosphate and potash, were wildly in error for nitrogen. The uncritical application of Mitscherlich's coefficients to field conditions had given rise to such books as " Nations Can Live at Home," in which O. W. Willcox expounded a so-called science of agrobiology and maintained that crop yields could be enormously increased by fantastically heavy dressings of inorganic nitrogen fertilisers.

Another by-product of fundamental scientific and immediate practical interest was the establishment of the fact that, though farmyard manure reduces the responses to given amounts of phosphate or potash fertilisers, the crop responses to inorganic nitrogen are almost the same in the presence as in the absence of farmyard manure. Previously it was commonly assumed that the nitrogen in farmyard manure necessarily reduced the response to inorganic nitrogen. Numbers of field experiments had been conducted to find the nitrogen-fertiliser equivalent of farmyard manure. The true situation appears to be that the improved soil conditions resulting from the use of farmyard manure enable the plant to respond to considerably more nitrogen than is supplied in the farmyard manure. There is, therefore, no need to cut down nitrogen fertiliser dressings where farmyard manure has been given. This result affords a good illustration of the general recommendation that farmyard manure and inorganic fertilisers should be regarded as complementary and not as alternative materials.

Survey of fertiliser practice

The actual increases in food production resulting from a given amount of fertiliser depend on the way in which it is used by farmers. In order to obtain better information on this subject the two Departments pressed for a national survey to discover how farmers actually used their fertilisers, to what crops they were applied, what were the amounts of dressings, and how these varied from farm to farm and district to district.

A preliminary survey of a small district of Hertfordshire was undertaken by Mr. H. W. Gardner of the Hertfordshire Farm Institute primarily to test whether the collection of such information was practicable. A systematic Survey of Fertiliser Practice was eventually commenced in April, 1942 in three Advisory Provinces, Bristol, Cambridge and Leeds. The results were utilised as they became available as an aid in framing policy, and a preliminary account of the results of the first three provinces has been published (5). The survey is conducted by field workers under the direction of the Advisory Chemists. These workers visit a random selection of farms, and on each farm select at random one field of old arable land and one of new arable land for each crop grown, and also one or more permanent grass fields. The amounts and compositions of the fertilisers applied to these fields and the crops grown over the preceding three years are ascertained from information given by the farmer, and soil samples are taken for analysis from one old arable, one new arable and one grass field.

The survey has provided quantitative evidence to substantiate a number of general impressions, but it has also revealed certain unsuspected defects. Thus it was to be expected that farmers in the pre-war grassland districts would use less fertiliser on their new arable crops than farmers in the old arable areas. It was not, however, realised how generally farmers would fail to recognise the deficiencies of lime and phosphate in their newly ploughed grassland. These two facts taken together had the result that cereals on the new arable land received on the average less phosphate than those on the old arable land. A substantial improvement in the use of limited rations of phosphate could have been effected had farmers

as a whole not overlooked the important difference in nutrient status between old arable and old grassland. Part of the blame for this mistake must be attributed to over-generalised statements about the nature of stored-up fertility. Old grassland tends to accumulate nitrogen in organic matter (humus) but it generally becomes deficient in available phosphate and lime, especially in the wetter districts. When old grassland is ploughed up it may supply adequate or sometimes even excessive amounts of readily available nitrogen, but quite inadequate amounts of lime and phosphate for arable crops. Soil fertility is a complex of many factors, and a potentially fertile soil may still lack one or more of the essential plant nutrients.

PUBLICATIONS

1. Crowther, E. M. and Yates, F. 1941. *Fertiliser policy in wartime : The fertiliser requirements of arable crops.* Emp. J. Exp. Agric. **9**, 77-97.

In order to formulate a flexible fertiliser policy which will ensure maximum agricultural production and make the best use of available fertiliser supplies, all published results of one-year fertiliser experiments conducted since 1900 in Great Britain on the main arable crops, and also of similar series of experiments in other northern European countries, have been summarised.

The main conclusions are as follows :

(*a*) The responses to phosphate and potash are substantially reduced when dung is applied, but crops are equally responsive to inorganic nitrogen on dunged and undunged land. Consequently smaller dressings of phosphate and potash are required on dunged land, but no reduction should be made in the nitrogenous dressings.

(*b*) The pre-war level of nitrogenous manuring, both in absolute amount and relative to that of the other fertilisers, was too low, particularly where dung was also given. Considerable increases in agricultural production would result from the greater use of nitrogen, especially on cereals.

(*c*) Additional phosphate is needed for root crops, especially in the wetter districts and on phosphate-deficient soils, including much of the newly ploughed grassland. Cereals also need phosphate on these deficient soils, but not on old arable land in good condition.

(*d*) The general policy of making fertilisers in short supply available only for the most responsive crops (already adopted in the case of potash) is the correct one. Potatoes should receive potash, even in the presence of dung, unless supplies are very short.

(*e*) The responses to phosphate and potash (in contrast to nitrogen) vary markedly with soils and districts. Consequently, in order to ensure the most efficient utilisation of soil reserves and fertiliser supplies, local knowledge or soil analysis should be used as far as possible.

2. Crowther, E. M. 1941. *Making the most of fertilisers. Farmer and Stockbreeder*, **55**, 386.

3. Crowther, E. M. 1942. *Nitrogen : a cycle of benefit. Farmer and Stockbreeder*, **56**, 349.

A general article on the value of sulphate of ammonia in the food production campaign.

4. Crowther, E. M. 1942. *Fertiliser policy on the farm.* J. Min. Agric. **49**, 68–79.

The fertiliser permit scheme for England and Wales for the 1942-43 season is described, and recommendations given for utilising to best advantage the amounts of phosphate and potash available.

5. Crowther, E. M. 1942. *Manuring under a fertiliser rationing scheme.* J.R.A.S.E., **103**, 150-160.

The war-time use of fertilisers is discussed in relation to the supplies available, the rate of action and residual values of fertilisers, and the conservation of plant foods on the farm.

6. Crowther, E. M. 1945. *Fertilisers during the war and after.* Bath and West and Southern Counties Society. Pamphlet No. 13, pp. 51.

A review of the wartime developments and future prospects in the use of fertilisers in Great Britain. The results of large numbers of field experiments are summarised as average responses to increasing amounts of nitrogen, phosphoric acid and potash under various conditions, and then used to show how the most profitable dressings can be worked out. Practical recommendations are compared with those obtainable under the wartime rationing schemes, and with the actual average practice of farmers as revealed in random sampling surveys. Attention is directed to a number of points in which useful improvements and economies could be made in the better use of farmyard manure, ground limestone and fertilisers. The relative merits of some of the alternative fertilisers are considered, and some promising new developments are outlined. Detailed tables are given to show the composition and relative costs of the principal straight fertilisers and compound fertilisers, the advantage of using a restricted number of standard compounds, and some current discrepancies between the relative costs of concentrated and ordinary compound fertilisers.

7. Yates, F., Boyd, D. A., and Mathison, I. 1944. *The manuring of farm crops : Some results of a survey of fertiliser practice in England.* Emp. J. Exp. Agric., **12**, 164-176.

The report presented some of the main findings of the survey which had immediate relevance from the point of view of improving the use of fertilisers.

Generally speaking, districts which have always depended mainly on arable cropping use adequate amounts of fertilisers, and make satisfactory differentiation between the needs of different crops. Even in these districts, however, the special needs of newly ploughed-out grassland have not been fully recognised, and crops tend to be manured without regard to the land on which they are grown. The report covers counties in the Advisory Provinces of Cambridge, Bristol and Leeds, and in the main the report relates to the manuring of the 1942 crops.

Farmers in the dairy and cattle-raising districts of the west of England and Yorkshire, who before the war had had little experience of arable farming, are much less " fertiliser conscious " than farmers in the eastern arable counties, and make insufficient use of fertilisers, even on old arable land. For example, the manuring of root crops is frequently ill balanced and inadequate in the western counties ; although very large supplies of farmyard manure are available, almost one-third of the root acreage received none, and many fields received no phosphate or no nitrogen. Even within the chief arable districts there were many farms, mainly in grass before the war (e.g., in West Bedford and South Essex), which make less effective use of fertilisers than their neighbours with greater experience of arable farming.

As a consequence, the use of lime and phosphate on new arable land has been quite inadequate over most of the surveyed area. The survey has confirmed (what has already been frequently emphasised) that new arable land is generally both much more acid and much more deficient in phosphate than old arable, but it is apparent that except in one or two districts this land has received less lime and less phosphate in recent years than has the old arable land.

The failure to recognise the function of farmyard manure as a source of phosphate, and more particularly, potash, is also striking. The survey shows that farmers require encouragement to use mixtures with a lower proportion of phosphate and potash where farmyard manure is also given.

The failure to distinguish clearly between the different action of the various plant nutrients has also led to an inadequate use of nitrogen on cereals grown after roots, presumably owing to the belief that the heavy manuring of the roots will have led to sufficient stored-up fertility. Certainly in those cases where only inorganic nitrogen has been used to manure the root crop, there is every reason to give a reasonably nitrogenous dressing to the following corn. There are also wide differences from farm to farm in the use of nitrogen on cereals, and it is clear that some farmers, at least, could profitably make greater use of this fertiliser. Only half the acreage of cereals in the surveyed provinces actually received nitrogen, and it is unlikely that a higher proportion receives nitrogen in the country as a whole.

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For Farmers

"MANURING FOR HIGHER CROP PRODUCTION," by Sir E. J. Russell, D.Sc., F.R.S., 1917. The University Press, Cambridge. 5/6.

"ARTIFICAL FERTILIZERS IN MODERN AGRICULTURE," by Sir E. J. Russell, D.Sc., F.R.S. Bulletin No. 28, Ministry of Agriculture and Fisheries, Third Edition, revised 1939. H.M. Stationery Office, or from the Secretary, Rothamsted Experimental Station, Harpenden. Cloth, 4/6 post free : or paper cover, 3/5 post free.

"WEEDS OF FARMLAND," by Winifred E. Brenchley, D.Sc., F.L.S., 1920. Longmans, Green & Co., 39 Paternoster Row, London, E.C.4. 12/6.

ROTHAMSTED CONFERENCE REPORTS : being papers by practical farmers and scientific experts. Obtainable from the Secretary, Rothamsted Experimental Station, Harpenden, Herts.

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*" Soil Conditions and Plant Growth," by E. J. Russell, D.Sc., F.R.S. Seventh Edition, 1937. 21/-.

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" Fifty Years of Field Experiments at the Woburn Experimental Station," by E. J. Russell, D.Sc., F.R.S., and J. A. Voelcker, C.I.E., M.A., Ph.D., with a Statistical Report by W. G. Cochran, M.A. (Rothamsted Statistical Department). 1936. 21/-.

" The Feeding of Crops and Stock," by A. D. Hall, K.C.B., F.R.S., Parts I and II revised by W. G. Ogg, M.A., Ph.D. Third Edition, 1944. John Murray, Albemarle Street, London, W.1. 12/-.

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* Out of print.

"PLANT NUTRITION AND CROP PRODUCTION" (being the Hitchcock Lectures, 1924, University of California), by E. J. Russell, D.Sc., F.R.S. The University of California Press and the University Press, Cambridge. 12/6.

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The following are obtainable from the Secretary, Rothamsted Experimental Station, Harpenden, Herts.

"AGRICULTURAL INVESTIGATIONS AT ROTHAMSTED, ENGLAND, DURING A PERIOD OF 50 YEARS," by Sir Joseph Henry Gilbert, M.A., LL.D., F.R.S., etc. 1895. 3/6.

"GUIDE TO THE EXPERIMENTAL PLOTS, ROTHAMSTED EXPERIMENTAL STATION, HARPENDEN." 1913. John Murray, 50 Albemarle Street, W. 1/-.

"A DESCRIPTIVE CATALOGUE OF PRINTED BOOKS ON AGRICULTURE FROM 1471 TO 1840, CONTAINED IN THE ROTHAMSTED LIBRARY." Second Edition, 1940. Cloth cover, 15/-; paper cover, 12/-. Packing and postage extra:—British Isles, 9d.; Overseas, Dominions and other countries, 1/3.

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"LESSONS ON SOIL," by E. J. Russell, D.Sc., F.R.S. 1926. The University Press, Cambridge. 3/-.

For General Readers

"THE FARM AND THE NATION," by E. J. Russell, D.Sc., F.R.S. 1933. George Allen and Unwin, Ltd., 40 Museum Street, London, W.C.1. 7/6.

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"THE POSSIBILITIES OF BRITISH AGRICULTURE," by Sir Henry Rew, K.C.B., and Sir E. J. Russell, D.Sc., F.R.S. 1938. 1/-. Obtainable from the Secretary, Rothamsted Experimental Station, Harpenden, Herts.

"PERSONAL REMINISCENCES OF ROTHAMSTED EXPERIMENTAL STATION," 1872-1922, by E. Grey, formerly Superintendent of the Experimental Fields. 5/-. Obtainable from the Secretary, Rothamsted Experimental Station, Harpenden, Herts.

"COTTAGE LIFE IN A HERTFORDSHIRE VILLAGE," by E. Grey. 1935. A companion volume to "PERSONAL REMINISCENCES OF ROTHAMSTED EXPERIMENTAL STATION." Fisher, Knight & Co., St. Albans. 3/6. (Out of stock).

"ENGLISH FARMING," by E. J. Russell. 1941. William Collins Sons & Co., Ltd., 10/12 Bow Street, Covent Garden, W.C.2. 4/6.

Other Books by Members of the Staff

"EVOLUTION, HEREDITY AND VARIATION," by D. W. Cutler, M.A., F.L.S. 1932. Christophers, 22 Berners Street, London, W.1. 4/6.

"STATISTICAL TABLES FOR BIOLOGICAL, MEDICAL AND AGRICULTURAL RESEARCH," by R. A. Fisher, M.A., Sc.D., F.R.S., and F. Yates, Sc.D. 1938. Oliver & Boyd, Edinburgh. 12/6.

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"MICROBES BY THE MILLION," by Hugh Nicol, Ph.D. 1939. Penguin Books, Harmondsworth, Middlesex. 9d.

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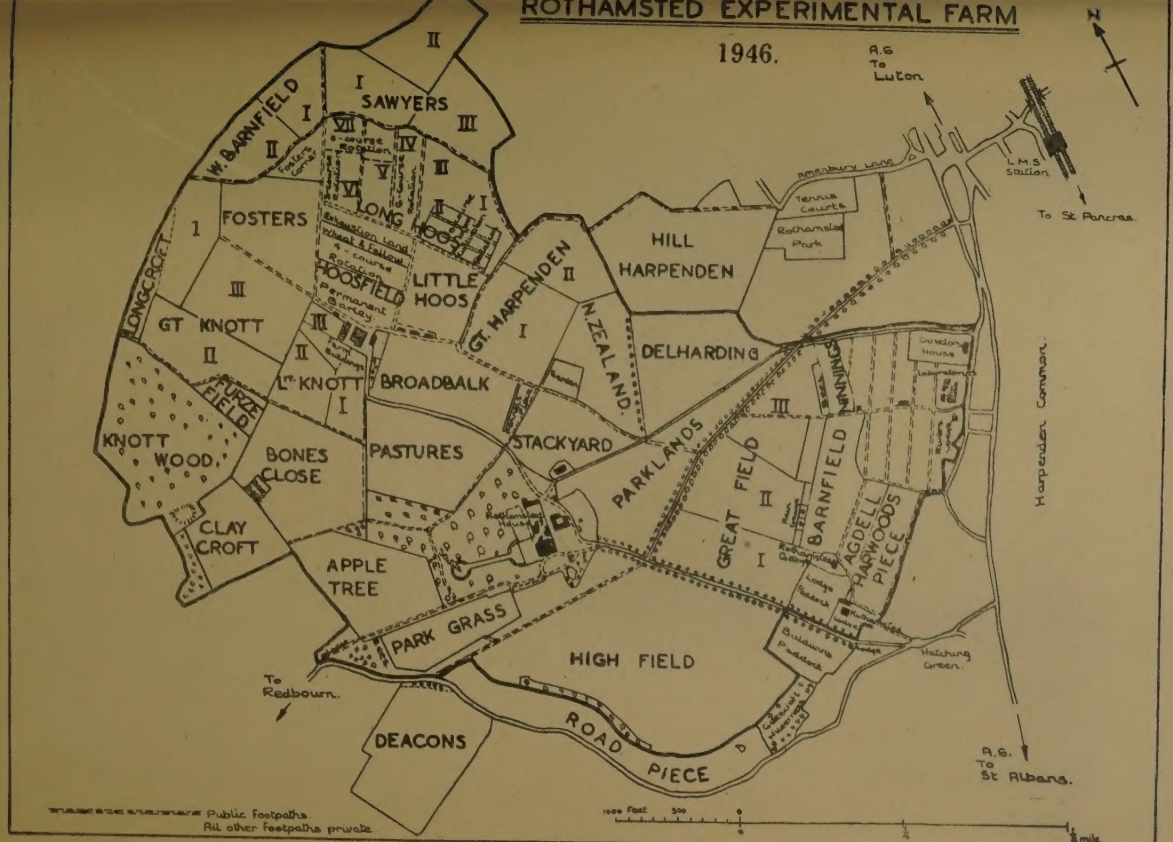
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